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PHYSIOLOGICAL, BIOMECHANICAL, AND MAXIMAL PERFORMANCE EVALUATION OF MEDIUM RUCKSACK PROTOTYPES

by

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14. ABSTRACT
This report documents an evaluation of two prototypes of a medium-size rucksack. One prototype had a padded hip belt and a bag mounted on a frame. The other had an unpadded hip belt and a frameless bag. Eight Army enlisted men participated in the assessment of the relative effects of the prototype rucksacks on physiological, biomechanical, and maximal performance measures. The men also completed opinion surveys regarding the prototypes. The men were tested in a 17-kg fighting load alone and with the addition of each prototype. Both prototypes were loaded to a mass of 23 kg. Times to complete 30-m rushes and an obstacle course run did not differ between the prototypes, but were significantly slower than without a rucksack. Rate of oxygen uptake was recorded during treadmill walking at 0% and 9% grades and scaled to body mass. These data yielded higher energy consumption with than without a rucksack, but there was no difference between the prototypes. Spatio-temporal gait variables and ground reaction force variables were computed from kinematic and kinetic data recorded during walking and running. These data revealed differences between the fighting load alone and with the addition of a rucksack, but there were few differences between the two prototypes. The men's opinions favored the prototype with the padded hip belt and frame; six of seven men selected this prototype as the item they would prefer to use as their Army rucksack.

15. SUBJECT TERMS

LEGS	LOCOMOTION	METABOLIC COST	OBSTACLE COURSE	ENERGY EXPENDITURE
GAIT	RUCKSACKS	LOADS(FORCES)	RANGE OF MOTION	PORTABLE EQUIPMENT
WALKING	BACKPACKS	BIOMECHANICS	PERFORMANCE(HUMAN)	TEST AND EVALUATION
RUNNING	USER NEEDS	LOAD-CARRYING	ARMY PERSONNEL	PHYSIOLOGICAL EFFECTS
SURVEYS	PROTOTYPES	OXYGEN UPTAKE	HUMAN FACTORS ENGINEERING	MOBILITY
OPINIONS	TREADMILLS	MOLLE(MODULAR LIGHTWEIGHT LOAD CARRYING EQUIPMENT)		

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PREFACE

The study reported here was carried out during the period from October 2010 to May 2011 by personnel of the Center for Military Biomechanics Research, Natick Soldier Research, Development and Engineering Center, U.S. Army Soldier Systems Center, Natick, MA. The purpose of the study was to provide an assessment of the physiological, biomechanical, and maximal performance effects of prototypes of a medium rucksack being considered for adoption as a standard Army item.

The effort was funded by the Product Manager-Soldier Clothing and Individual Equipment (PM-SCIE), Program Executive Office-Soldier (PEO-Soldier), under a project entitled “Biomechanical Testing and Human Factors” (MIPR #0FDATSBIOM). Mr. John Kirk, PM-SCIE, PEO-Soldier, served as the Project Officer.

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Special recognition is due to the study volunteers, who were enlisted men assigned to Headquarters Research and Development Detachment, NSRDEC.

EXECUTIVE SUMMARY

Between October 2010 and May 2011, the Center for Military Biomechanics Research, Natick Soldier Research, Development and Engineering Center, conducted a laboratory-based study of two rucksack prototypes of intermediate size (0.049 m^3 [3000 $in.^3$]) that were developed in response to needs expressed by Operation Enduring Freedom (OEF) Soldiers for an alternative to the Army's two current assault pack designs. The findings from this study provided Product Manager-Soldier Clothing and Individual Equipment (PM-SCIE), Program Executive Office-Soldier (PEO-Soldier), with information to evaluate the acceptability of the prototypes for adoption as standard Army items.

Background and Purpose. The Modular Lightweight Load-carrying Equipment (MOLLE) system, the Army's load-bearing system, includes a large rucksack with a volume of 0.065 m^3 (4000 $in.^3$) and a small assault pack with a volume of 0.033 m^3 (2000 $in.^3$). Soldiers deployed in OEF identified a need for a MOLLE rucksack that could accommodate gear and supplies for missions of up to 72 h, not accommodated by the current small pack, without the cumbersome mass and weight of the large pack. The MOLLE Team, PM-SCIE, PEO-Soldier, created three prototypes of a medium rucksack, which were tested in a field evaluation. Based on feedback from the Soldiers who participated in the field testing, one prototype was dropped from further consideration and the other two were modified.

The purpose of this investigation was to quantify the physiological, biomechanical, and maximal performance effects of the two modified rucksack prototypes and to obtain feedback on them from Soldiers. In addition to the testing of the two rucksacks, a baseline condition, which did not include a rucksack, was tested. The designs of the bag portions of both modified prototypes were similar in size and shape. The bags of both prototypes had a volume of 0.049 m^3 (3000 $in.^3$). The rucksacks differed in design of the suspension system, including the shoulder straps and the hip belt. One of the prototypes, identified as Ruck B, utilized a padded hip belt and a bag that was mounted on a frame of molded polymeric material. The other prototype, identified as Ruck C, utilized a hip belt that was not padded and a frameless bag. The front of Ruck C, the surface of the rucksack closest to the user's back, had two vertical cylinders comprised of fabric filled with high-density foam. The cylinders extended vertically and were located to parallel the left and right edges of the back plate of an armor vest. The cylinders were designed to be close to the plate edges, such that they "cradled" the back plate to prevent the rucksack from exerting pressure on the plate, which could result in pain and discomfort on the user's back.

Method. Eight Army enlisted men volunteered to participate in the study. Throughout testing, they were outfitted in a fighting load configuration, which included an Improved Outer Tactical Vest with front and back plates, a Tactical Assault Panel, and an Advanced Combat Helmet. They also carried a simulated M4 carbine. The rucksack prototypes were loaded with Soldier items to obtain a mass of 23 kg (50.7 lb), which included all components of the rucksack itself and the load in it. Each volunteer was tested with the fighting load alone (No Ruck control condition) and with each of the rucksacks added to the fighting load (Ruck B and Ruck C conditions). In the No Ruck condition, the total mass on the body, including all clothing and equipment, was 17 kg (37.5 lb). In the Ruck B and the Ruck C conditions, the total mass on the body was 40 kg (88.2 lb). Physiological data were collected during walking at 1.34 $m \cdot s^{-1}$

($3.00\ mi \cdot h^{-1}$) on 0% and 9% grades. Biomechanical data were collected during the walking and also during running at $2.24\ m \cdot s^{-1}$ ($4.47\ mi \cdot h^{-1}$) on a 0% grade. These locomotor activities took place on an instrumented force plate treadmill. Maximal performance tests consisted of a 30-m rush, a repetitive box lift and carry activity, and traversal of a combined outdoor obstacle and indoor military operation on urbanized terrain (MOUT) course. Subjective assessments were made by administration of questionnaires at various points in the testing and administration of a questionnaire at the end of testing to obtain the Soldier-volunteers' opinions of the rucksacks. Human factors issues pertaining to donning and doffing of the rucksacks and compatibility of the rucksacks with other equipment worn and activities performed were also addressed by the investigators.

Results. The data obtained on energy consumption, gait biomechanics, and maximal performance revealed significant differences between the fighting load alone and the fighting load plus either rucksack. The additional mass on the body imposed by the loaded rucksacks resulted in higher energy consumption per unit body mass during walking, higher magnitude ground reaction forces per unit body mass during walking and running, and slower times to complete two of the three maximal performance tests compared with the fighting load alone; the box lift and carry was not significantly affected by the load condition worn. Analyses of the data did not reveal significant differences between the rucksacks on these quantitative measures. Further, the volunteers' responses on the questionnaires did not indicate extensive differences between the two rucksacks. However, six of seven volunteers selected Ruck B as the rucksack they would prefer to use in the future as their Army rucksack; the seventh volunteer selected Ruck C. Among the reasons given for preferring Ruck B were that the pack bag fit well against the back and that the rucksack was stable on the body during movement.

Conclusions. The findings pertaining to the negative effects of load mass revealed in comparisons of data for the fighting load with data for the fighting load plus either rucksack are evidence of the detrimental impacts that carrying external loads have on the fighting ability and operational effectiveness of Soldiers. The findings also emphasize the importance to the success of military operations of minimizing the load borne by the individual Soldier. The lack of significant differences between Rucks B and C with regard to the quantitative measures of energy consumption, gait biomechanics, and maximal performance was not unexpected, given that the rucksacks were equally weighted, had similar centers of mass, and had pack bags that were of similar size and shape. From the perspectives of the volunteers, however, there were apparently substantial differences between the two rucksacks as six of seven volunteers selected Ruck B as the rucksack they would prefer to use in the future.

Recommendations. The overall results of this study favored Ruck B as the design for the Army's medium rucksack. There were, however, some features of Ruck B in need of improvement or further testing. These included: excessively long shoulder straps; adjustment of the shoulder straps that is not intuitive; and difficulty shouldering the M4 carbine due to the shoulder straps of the rucksack and the armor vest.

PHYSIOLOGICAL, BIOMECHANICAL, AND MAXIMAL PERFORMANCE EVALUATION OF MEDIUM RUCKSACK PROTOTYPES

INTRODUCTION

This report documents a laboratory-based study of two prototypes of a medium rucksack. The study was conducted by the Natick Soldier Research, Development and Engineering Center (NSRDEC), between October 2010 and May 2011, to assess the physiological, biomechanical, and maximal performance effects of the rucksack prototypes relative to each other and to a control condition. The prototypes had the same volume and carrying capacity, but differed in design of the suspension system and in the interface between the rucksack bag and the user's back. The control condition did not include a rucksack. The purpose of the study was to provide information for evaluating the acceptability of the prototypes for adoption as standard Army items, which would add another option to smaller and larger assault pack alternatives currently in the Army system.

The effects of the rucksack prototypes and the control condition on energy consumption during walking and running and on walking and running movement patterns were analyzed in the current study. Physical performance measures involving militarily relevant tasks requiring mobility and agility (30-m rush, repetitive box lifting and carrying, and an obstacle course run) were also included in this study, along with assessments of range of motion (ROM) about body joints and opinions of Soldier-volunteers regarding the rucksacks.

Each rucksack was loaded with military gear to achieve a weight of 23 kg (50.7 lb), inclusive of the components of the rucksack itself. The weight approximates the load that the prototypes were designed to carry. The Soldiers participating in the study were also tested without a rucksack. Throughout the testing, the Soldiers were outfitted in Improved Outer Tactical Vest (IOTV) body armor with front and back Enhanced Small Arms Protective Insert (ESAPI) plates, a Tactical Assault Panel (TAP) carrier for ammunition and grenades, and an Advanced Combat Helmet (ACH).

The Modular Lightweight Load-carrying Equipment (MOLLE) system is the current Army equipment for carrying individual Soldier loads. The system includes a large rucksack with a volume of 0.065 m^3 (4000 $in.^3$) and an assault pack with a volume of 0.033 m^3 (2000 $in.^3$). Feedback from deployed infantry in Operation Enduring Freedom (OEF) identified a need for an intermediate-size pack that could accommodate gear and supplies needed for missions of up to 72 h. The addition of a medium rucksack to the MOLLE system could fill a capability gap by reducing the bulk and possible overloading that is often associated with the use of the large rucksack during shorter missions and by providing sufficient capacity to carry loads that are too large for the assault pack.

The two prototypes tested in the current study were created by the MOLLE Team, Product Manager-Soldier Clothing and Individual Equipment (PM-SCIE), Program Executive Office-Soldier (PEO-Soldier). The team initially created three prototypes of a medium MOLLE rucksack to meet the needs of deployed infantry in OEF. The prototypes had a volume of

0.049 m^3 (3000 $in.^3$). They were designed to carry approximately 23 kg (50.7 lb) of Soldier gear and to be compatible with wear of the IOTV body armor with front and back ESAPI plates. The designs of the bag portion of these initial prototypes were similar in size, shape, and volume. The three rucksack prototypes differed in design of the suspension system, including the shoulder straps and the hip belt. They also differed in the interface between the rucksack bag and the user's back.

The three initial rucksack prototypes underwent field testing by Soldiers stationed at Fort Knox, KY, and Schofield Barracks, HI (Richardson, 2010). Based on feedback from the field test (Richardson, 2010), the MOLLE Team made changes to two of the rucksacks and dropped the third one from further consideration. The MOLLE Team then requested that the Center for Military Biomechanics Research, NSRDEC, conduct the laboratory-based study documented in this report of the two modified rucksacks in order to assess the acceptability of the changes made and to obtain quantitative data on Soldiers to augment the subjective information obtained on Soldiers in the field test (Richardson, 2010).

Field Testing of the Rucksack Prototypes

One of the three initial prototypes devised by the MOLLE Team, Ruck A, had a padded hip belt and a frameless bag. Another initial prototype, Ruck B, had a hip belt that was not padded and a bag that was mounted on a frame of molded polymeric material. A third initial prototype, Ruck C, had a hip belt that was not padded and a frameless bag. The front of Ruck C, the surface of the rucksack bag closest to the user's back, had two vertical cylinders, which were comprised of fabric and filled with high-density foam. The cylinders extended vertically from about the midpoint of the length of the rucksack bag and were positioned toward the left and the right outer edges of the bag. The cylinders were placed to parallel the left and right edges of the back plate of an armor vest. The cylinders were designed to be close to the plate edges, such that they "cradled" the back plate for the purpose of preventing the rucksack from exerting pressure on the plate thereby inducing pain and discomfort on the load carrier's back.

In the field testing of the three initial prototypes, 30 Soldiers stationed at Fort Knox, KY, and 30 Soldiers at Schofield Barracks, HI, served as test participants (Richardson, 2010). With one exception, the Soldiers were men. A number of military occupational specialties were represented, including infantry. Over a 10-day period, each Soldier used each of the three initial prototypes while executing a number of test activities. The activities included donning and doffing the rucksacks, aiming an M4 carbine, low crawling, rushing, and foot marching. The donning and the doffing were timed. For the other activities, the Soldiers were given questionnaires upon activity completion and asked to rate various characteristics of the rucksacks on Likert scales (e.g., *very comfortable*/*very uncomfortable*, *very good*/*very bad*). The Soldiers' written comments were also solicited. The rucksack donning and doffing were carried out while the Soldiers were wearing the IOTV with front, back, and side plates, as well as when the IOTV was not worn. The rifle aiming, low crawling, and rushing entailed use of the rucksacks, an IOTV with the plates, a MOLLE fighting load vest, an ACH, and an M4 carbine. The road marching was conducted with this same equipment and also without the IOTV, the fighting load vest, the helmet, and the M4.

Donning and doffing times were quite similar for the three initial prototypes (Richardson, 2010). Donning took longer when the IOTV was worn than when it was not, averaging 40 s or less with the IOTV and 25 s or less without it. Doffing took less than 10 s, regardless of whether body armor was worn. The Soldiers' comments pertaining to aiming the M4 carbine were also similar for all prototypes. A frequently occurring comment was that the butt of the weapon slipped off the shoulder strap of the rucksack as the Soldiers attempted to "pocket" the weapon. Another comment common to all rucksacks was in regard to aiming when in the prone position. In this position, some of the Soldiers reported that the top of the rucksack contacted the brim of the helmet, making it difficult to raise their heads to sight the weapon and also pushing the helmet lower on their foreheads. A number of Soldiers commented on stability of the rucksacks during performance of the rushes. However, there was no unanimity regarding whether a particular rucksack moved extensively on their backs, either side to side or vertically, or remained in place as the Soldiers ran during their rushes.

The foot marches were conducted on paved roads and dirt paths over a distance of 5 km without and with the IOTV, the fighting load, and the helmet. Soldiers packed the rucksacks with military gear prior to the march. For the marches conducted without the IOTV and the other items, the masses of the loaded packs were between 22.7 and 27.2 kg. When the IOTV and the other items were worn, the rucksacks were loaded to between 13.6 and 18.1 kg. The majority of the Soldiers indicated that all three rucksacks were of sufficient size to accommodate the gear that they would take on a 72-h mission (Richardson, 2010). With regard to marching with the rucksacks, there was a variety of opinions about each prototype concerning pack bag stability and acceptability of the location of the bag on the back relative to the shoulders and the hips. There were comments, as well, that occurred more frequently for one rucksack version than another. The padded hip belt on Ruck A received positive comments for bearing some of the load weight, although it was also mentioned that the hip belt loosened during the march. Some Soldiers found that the shoulder straps of Ruck B were difficult to adjust and that the adjustment straps for the shoulder straps were too long and became tangled. The frame of Ruck B received positive comments from some Soldiers who thought that it contributed to the stability of the load. The unpadded hip belts of Rucks B and C were viewed negatively by some Soldiers for not bearing any of the load. The foam cylinders on Ruck C were not liked by some of the Soldiers. One reason given was that the cylinders were too long and dug into the body below the lower edge of the IOTV (Richardson, 2010).

After completing all test activities wearing each of the three rucksacks, the Soldiers were asked to give an overall rating reflecting their degree of *like*/*dislike* of each initial prototype version (Richardson, 2010). Mean ratings given to Rucks A and B were similar and positive (i.e., *like*); the mean rating for Ruck C was negative (i.e., *dislike*). The Soldiers were also asked to select their preferred rucksack. The majority (n = 42/58) selected Ruck B; very few (n = 2/58) selected Ruck C.

Based on feedback from the Soldiers (Richardson, 2010), the MOLLE Team made changes to Rucks B and C and dropped Ruck A from further consideration because of its similarity to Ruck B. The feature on Ruck A most liked by field study participants was the hip belt. Therefore, the hip belt on Ruck B was replaced with a padded hip belt similar to that on

Ruck A. The foam cylinders on Ruck C were shortened to avoid the problem of the cylinders digging into the user's back below the armor vest.

Energy Consumed While Carrying External Loads on the Body

The physiological measure recorded and analyzed in the current study was the rate of oxygen uptake ($\dot{V}O_2$), which was used as an indicator of energy consumption for Soldier-volunteers walking with each of the two rucksack prototypes and without a rucksack. For someone eating a normally balanced diet, rate of energy utilization during exercise is closely correlated with $\dot{V}O_2$. A large amount of research has been conducted to evaluate the effects on oxygen consumption of external loads added to the body (Knapik, Harman, & Reynolds, 1996). Much of this work addressed issues related to energy usage when carrying loads on the back in rucksacks. In studies done on marching with rucksacks, it has been found that increases in energy consumption are directly related to increases in the mass of the load, as well as to increases in the speed of walking and the inclination of the walking surface (Beekley, Alt, Buckley, Duffey, & Crowder, 2007; Pandolf, Givoni, & Goldman, 1977; Polcyn et al., 2002; Sagiv, Ben-Sira, Sagiv, Werber, & Rotstein, 1994; Soule, Pandolf, & Goldman, 1978).

When a rucksack was not worn in the current study, the external load on the body was less, by about 23 kg (50.7 lb), than when either of the rucksack prototypes was used. Based on the findings reported in the literature (Pandolf et al., 1977; Polcyn et al., 2002; Sagiv et al., 1994; Soule et al., 1978), the lighter load on the body when a rucksack was not worn would be expected to be reflected in lower $\dot{V}O_2$ levels during walking compared with the levels achieved when either rucksack prototype was carried.

The extant literature comparing energy usage with rucksacks loaded to the same weight, but differing in design, is not as extensive as the research into load weight effects. Thus, the relative effects of the two rucksack prototypes on $\dot{V}O_2$ levels were difficult to predict. The limited literature on design effects includes investigations of rucksacks with different suspension systems, frame structures, and pack bag designs (Bobet & Norman, 1984; Harman et al., 1999a, 1999b; Holewijn, 1990; Kirk & Schneider, 1992; Obusek, Harman, Frykman, Palmer, & Bills, 1997; Patton, Kaszuba, Mello, & Reynolds, 1990; Roberts, Reading, Daley, Hodgdon, & Pozos, 1996; Stuempfle, Drury, & Wilson, 2004; Winsmann & Goldman, 1976). The findings from studies to date of rucksacks loaded to the same weight, but differing in design, suggest that elements likely to affect energy consumption are those that entail differences between rucksacks in the location of the load center of mass (COM) relative to the load carrier's back (LaFiandra, Holt, Wagenaar, & Obusek, 2002; Obusek et al., 1997).

Obusek et al. (1997) conducted a study specifically designed to investigate the effects of location of loads on the back. They recorded the $\dot{V}O_2$ of men walking on a level treadmill at $1.6\ m \cdot s^{-1}$ while carrying a backpack device, which consisted of a metal case attached to an external backpack frame. A 24.9-kg lead brick was placed in nine different positions within the case, ranging from high to low relative to the load carrier's back along the longitudinal axis and from close to away from the back along the anterior-posterior axis. The location along the medial-lateral axis could not be changed; in this location, the load was aligned with the approximate midline of the load carrier's back. The mass of the backpack and the brick totaled

34 kg. Obusek et al. (1997) found that $\dot{V}O_2$, expressed in milliliters per kilogram of body-plus-load mass per minute, varied with the location of the lead weight. The highest $\dot{V}O_2$ values were associated with a load position that was low and away from the back. The lowest $\dot{V}O_2$ values were obtained with the load high and close to the back.

Obusek et al. (1997) did not report on the COMs for the various load locations they investigated. In a subsequent effort, Norton et al. (2003) took measurements of the backpack device used by Obusek et al. (1997) to determine the COM at the different load positions. Norton et al. (2003) also measured the moment of inertia (MOI). The MOI of a body describes the distribution of mass about a specified axis of rotation and, therefore, is the inertial property that represents a body's resistance to angular acceleration (Hinrichs, Lallemant, & Nelson, 1982; Martin, Hinrichs, Shin, & Nelson, 1982).

Using reference axes that had an origin located at a lower corner of the backpack frame, Norton et al. (2003) found a difference in the COMs for the highest and the lowest load locations of 27.0 cm along the longitudinal axis. For the COM measurements taken along the anterior-posterior axis, the difference was smaller. The distance between the COM position farthest from the frame, and farthest from the load carrier's back, and the COM position closest to the frame was 11.0 cm. Relating the COM measurements to the results obtained by Obusek et al. (1997), the men who carried the backpack device while walking evidenced the lowest energy consumption when the COM along the longitudinal axis was relatively high and the COM along the anterior-posterior axis was relatively close to the frame (i.e., close to the load carrier's body).

Considering the MOIs about the longitudinal, anterior-posterior, and medial-lateral axes, Norton et al. (2003) found that the lower the load position and the closer the load to the frame, the smaller the MOI. Norton et al. (2003) also reported that some of the locations of the load had well-defined intermediate MOIs. Classification of a load position as having a well-defined intermediate MOI was based upon finding relatively large differences for the three axes between the highest and the middle MOI values and the middle and the lowest MOI values. When a body rotates about a principal axis that has the minimum or the maximum MOI value, a small disturbance to that rotation will not grow, and the body will continue to rotate about that axis. Therefore, the motion is considered to be stable (Greenwood, 1965; Wardle, 2001). However, rotation about an axis that has an intermediate MOI value is unstable, and the body will appear to be "out of control" (Greenwood, 1965; Wardle, 2001). The body will tend to rotate about the other two axes as well, which may make it difficult to control the rotation.

Aside from the work of Obusek et al. (1997) and Norton et al. (2003), little research has been done to relate the energy consumed by a load carrier to the inertial properties of the rucksack load being carried. It is not yet known how sensitive $\dot{V}O_2$ is to variations in load COM and MOI. The current study did not include controlled variations in the COM or the MOI of the two rucksack prototypes. However, data were obtained on the inertial properties of the rucksacks to use in assessing the results for the $\dot{V}O_2$ measure recorded during walking.

Effects on Gait Biomechanics of Carrying External Loads on the Body

In addition to measurement of $\dot{V}O_2$, biomechanical measures of gait were captured in the current study as the Soldier-volunteers walked and ran with the rucksack prototypes and without a rucksack. As is the case with the literature on $\dot{V}O_2$ as affected by loads on the body, much of the reported research on the biomechanics of load carrying has been focused on the effects of load weight. Research has demonstrated that increasing the load weight changes the kinematics, kinetics, and muscle responses of the human body during locomotion (Birrell & Haslam, 2010; Harman, Han, Frykman, & Pandorf, 2000; Hasselquist, Bensel, Kramer, Augustyn, & Banderet, 2009; Kinoshita, 1985; Martin & Nelson, 1986). Martin and Nelson (1986) examined the effects of load weight on spatial and temporal gait variables. They found that, with an increase in rucksack mass, both men and women had a higher step rate, shorter stride length, shorter swing time, and increased double support time, and that women showed a greater alteration in these kinematic variables than men. Stance time has also been found to increase with load mass (Harman et al., 2000; Hasselquist et al., 2009; Kinoshita, 1985).

A number of studies have been done in which kinetic data were acquired during walking to quantify the effects of varying load mass on ground reaction force (GRF). Peak vertical and peak anterior-posterior GRFs at foot contact with the ground have been found to increase as rucksack mass increases (Harman et al., 1999a, 1999b; Kinoshita & Bates, 1981). Polcyn et al. (2002) carried out correlational analyses on a number of GRF measures recorded while study participants walked on a level surface at a speed of 1.34 $m \cdot s^{-1}$ carrying rucksack loads of various masses. They examined the relationship between a range of load masses and the magnitude of the GRFs. The correlations revealed that about 88% of the variance in peak vertical force and 50% of the variance in peak braking force in the early stance period were attributable to total weight (body weight plus weight of the load carried). Based on the findings of investigations into load mass effects on biomechanical parameters (Harman et al., 1999a, 1999b; Kinoshita, 1985; Martin & Nelson, 1986; Polcyn et al., 2002), GRFs and values of spatial and temporal variables for walking and running were expected to reveal differences in the current study between a condition that entailed carrying a loaded rucksack and a condition in which a rucksack was not used.

As is the case with energy consumption, the effects that rucksacks of equal weight, but differing in design, are likely to have on biomechanical measures have been investigated to only a limited extent. Harman et al. (1999b) conducted a study of two rucksacks loaded to the same weights, 9.1 kg and 22.7 kg, but the designs of the rucksack bag, shoulder straps, and hip belt differed and the COM of one rucksack was higher than that of the other by 7 to 8 cm. Eleven male Soldiers serving as study participants wore basic equipment weighing approximately 16.8 kg, including an armor vest, a helmet, and a vest with pouches containing ammo and grenades. Testing, which consisted of the Soldiers walking at 1.34 $m \cdot s^{-1}$ on a level treadmill for about 5 min, was conducted with the basic equipment alone and with each of the loaded rucksacks. For both the 9.1-kg and the 22.7-kg rucksack loads, Harman et al. (1999b) obtained significant differences between the two rucksack designs for peak vertical GRF at foot contact and at push off, with the values of both variables being higher for the rucksack with the higher COM. In a second investigation employing the same study protocol, Harman et al. (1999a) tested two different rucksacks on 12 female Soldiers. The rucksacks again differed in design of the bag,

shoulder straps, and hip belt. Further, one rucksack COM was higher than the other by 5 to 6 cm. Again, peak vertical forces at foot contact and at push off were greater for the rucksack with the higher COM.

The paucity of research comparing different designs of rucksacks that are weighted equally made it difficult to predict the likely outcome in the current study when comparing Rucks B and C on biomechanical measures. However, data were acquired in the current study on the COMs and the MOIs of the rucksack prototypes to provide a basis for assessing the results of the kinematics and the kinetics recorded as the Soldier-volunteers walked and ran while carrying the prototypes.

Maximal Performance Tests for Assessing Effects of External Loads on the Body

A number of tests were used in the current study in order to obtain data on Soldier-volunteers' maximal performance. The tests were a series of five successive 30-m combat rushes, a repetitive box lift and carry test, and traversals of a combined obstacle and military operation on urbanized terrain (MOUT) course. The tests were selected for their military relevance and strong agility and maneuverability components. Studies done on the effects of load carriage on agility and performance of Soldier-related physical tasks have, like the research pertaining to energy cost and biomechanics, been focused mainly on assessing the impact of load mass. Holewijn and Lotens (1992) reported that backpack mass contributed to performance decrements in maneuvering through obstacles, hand-grenade throwing, running, and jumping. Similarly, Martin, Nelson, and Shin (1983) found that performance on an agility run decreased with an increase in load mass, and Knapik et al. (1997) found that times to complete a 20-km road march increased as load mass increased.

30-m Rush

The 3- to 5-s rush is a basic activity Soldiers are trained to perform that has been adapted as an objective test. Soldiers use the rush to move from one covered, protected location to another (U.S. Department of the Army, 2012). The rush involves rising from a prone to a standing position, running, stopping, and then returning to a prone position. Soldiers repeat the actions of the rush sequence as they move forward. The time spent in standing and running positions is limited to 3 to 5 s to avoid enemy fire. Harman, Frykman, Gutekunst, and Nindl (2006) developed a timed test based on the rush, which entailed completion of five successive 30-m rushes. Hasselquist et al. (2009) used the test in an assessment of two load-carriage systems and found the test to be sensitive to the mass of the load on the body. For these two systems, the total weight on the body, including clothing, individual military equipment, and a rucksack, was 36.5 kg and 42.2 kg. Hasselquist et al. (2009) also assessed time to complete the five 30-m rushes when the Soldier-participants wore only basic clothing, which weighed 9.1 kg and consisted of an Army Combat Uniform (ACU), combat boots, and an ACH. Analysis of time to complete all five rushes revealed that the time for the heaviest load was significantly longer than the times for the 36.5-kg and the 9.1-kg loads. The time for the 36.5-kg load was also significantly longer than that for the 9.1-kg load. Times to complete the individual rush segments were also analyzed. Hasselquist et al. (2009) found that segment times increased significantly

from the first to the fourth rush for both of the heavier loads, but time for the fifth rush was similar to that of the fourth for both of these loads. For the minimal load, there were no differences among the segment times.

From the findings of Hasselquist et al. (2009), it would be expected that the current study would reveal longer times to complete five rushes with the rucksacks than without them. There are no known investigations that reported 30-m rush times with rucksacks of equal weight and different designs. Thus, there was no basis for projecting whether the two rucksack prototypes used in the current study would yield time differences. However, Harman et al. (1999a, 1999b) did investigate time to carry out an activity that is similar to an activity that forms part of the 30-m rush test (i.e., time to move from a standing to a prone position and to return to a standing position). In studies done with men and with women carrying rucksacks loaded to 9.1 kg, which differed in design and in COM, Harman et al. (1999a, 1999b) did not obtain significant differences in times to complete the activity.

Repetitive Box Lift and Carry

A repetitive box lift task similar to the task included in the current study was used previously to assess the efficacy of various physical training programs by comparing the number of lifts accomplished before and after training (Harman et al., 1997; Knapik & Sharp, 1998; Sharp, Bovee, Boutilier, Harman, & Kraemer, 1989; Sharp & Legg, 1988). According to Pandorf et al. (2003), the box lift is a highly reliable test (intraclass correlation coefficient of .92-.94). A maximal-effort, timed, repetitive lifting test was used by Sharp, Harman, Boutilier, Bovee, and Kraemer (1993) to simulate the re-supply of a 155-mm self-propelled Howitzer. The final test score was the number of 41-kg boxes lifted to chest height in a 10-min period. Similar protocols with lighter weights have been used to examine the repetitive lifting capacity of women before and after progressive resistance training programs (Harman et al., 1997; Knapik & Gerber, 1996; Kraemer et al., 2001).

A variation of this task was used by Hasselquist et al. (2009) in their study of two load-carriage systems. Including clothing, individual equipment, and a rucksack, the external load on the body was 36.5 kg with one system and 42.2 kg with the other. Soldier-participants repeatedly lifted a 20.5-kg box from the floor and placed it on a 1.32-m-high shelf, keeping pace with a metronome set at 12 lifts/min. Testing ended when a participant could no longer keep pace with the metronome. Hasselquist et al. (2009) compared the number of boxes lifted when participants were wearing the load-carriage systems and when they were wearing only basic clothing and equipment with a mass of 9.1 kg. Hasselquist et al. (2009) reported that, compared with the basic clothing and equipment, significantly fewer boxes were lifted when either load-carriage system was being worn, but they did not find a difference between the two systems.

The repetitive box lift task used in the current study differed somewhat from the version employed by Hasselquist et al. (2009). The Soldier-volunteers lifted a 20.5-kg box from the floor, carried it 3.05 m, and placed it on a 1.32-m-high shelf. These actions were repeated for 5 min to obtain the number of boxes lifted and carried in that period. Thus, as tested in the current study, there was a carrying component to the task, and the volunteers were not paced by a metronome, but instead were encouraged to work as quickly as possible. Based on the results

obtained by Hasselquist et al. (2009), it was hypothesized for the current study that the number of boxes lifted would not differ between the two rucksack prototypes and that the best performance would be achieved when a rucksack was not worn. However, because of variations in task protocols, there was the possibility that findings for the current study would not parallel those reported by Hasselquist et al. (2009).

Combined Obstacle and MOUT Course Traversal

Timed runs of obstacle courses, which require such activities as jumping, crawling, climbing, and balancing, have been used extensively in studies to evaluate different designs of load-carriage equipment (Brainerd & Bruno, 1985; LaFiandra et al., 2003). Pandorf et al. (2003) reported that time to complete an obstacle course is a highly reliable measure (intraclass correlation coefficient of .92). The particular course used in the current study consisted of an outdoor obstacle layout and an immediately adjacent indoor MOUT layout. The time to complete both portions of the course was measured.

The combined obstacle and MOUT course has been used in previous studies of load-carriage equipment (Kirk et al., 2005; LaFiandra et al., 2003). Kirk et al. (2005) tested rucksacks varying in weight and in carrying capacity. They found that course completion times were sensitive to differences in weight on the body. Kirk et al. (2005) also found that larger rucksack volumes resulted in slower completion times, likely reflecting the difficulty of passing through small openings with the larger rucksacks or of controlling the inertia of the larger volume loads. LaFiandra et al. (2003) examined differences in course times for three load-carriage systems that were approximately equal in weight and included body armor with plates and a rucksack. The total weight on the body with each load-carriage system was about 32.7 kg. The rucksacks differed in design, but had similar COMs. Twelve Soldier-participants were timed as they traversed the combined obstacle and MOUT course in each of the three systems. LaFiandra et al. (2003) did not obtain significant differences in completion times among the systems. From the findings of Kirk et al. (2005) and LaFiandra et al. (2003), it was hypothesized that the Soldier-volunteers in the current study would complete the combined obstacle and MOUT course more quickly without than with a rucksack. Also, it was unlikely that the two rucksack prototypes would yield different course traversal times, given that the rucksack bags were of equal volume and of similar dimensions, unlike the rucksacks used by Kirk et al. (2005).

METHOD

Participants

Participants were eight U.S. Army enlisted men recruited from among the military personnel who serve as human research volunteers assigned to Headquarters Research and Development Detachment, NSRDEC. The men had recently completed Advanced Individual Training and were awaiting their first assignments to regular Army units. Their mean time in service was approximately 5 months. The men's experience carrying military loads was limited to several foot marches with loaded rucksacks that were conducted as part of their training.

The men volunteered to participate after being informed of the purpose of the study, the nature of the test conditions, the risks associated with the study, all procedures affecting a volunteer's well being, and a volunteer's right to discontinue participation at any time without penalty. Those who agreed to participate expressed their understanding by signing a volunteer consent form. The study was approved by the local Human Subject Research Determination Panel and was determined not to be human subject research according to the Federal Policy for the Protection of Human Subjects, U.S. Department of Defense, 32 Code of Federal Regulations Part 219.

Prior to participation in the study, all volunteers underwent medical screening, including a physical examination and clinical review of their medical records, with an emphasis on the musculoskeletal system. Individuals with a history of back problems, including herniated intervertebral discs or previous orthopedic injuries that limit the ROM about the shoulder, hip, knee, or ankle joint, were excluded from participation. Volunteers abstained from heavy and moderate exercise and alcohol consumption for 24 h prior to each day of testing. Summary statistics of the physical characteristics of the men are presented in Table 1.

Table 1. *Demographics of Study Volunteers (N = 8)*

Variable	Mean	Minimum	Maximum
Age (years)	24	20	26
Stature (cm)	176.2	165.7	186.2
Weight (kg)	75.0	60.9	108.0

Load Conditions

A standard fighting load was worn throughout testing. It consisted of an IOTV with front and back ESAPI plates, a TAP, an ACU, an ACH, and combat boots. A simulated M4 carbine was carried during all but two of the testing activities: the box lift and carry and the ROM assessment.

The two medium rucksack prototypes tested in the current study were the initial Rucks B and C that were modified following the field tests conducted at Fort Knox, KY, and Schofield Barracks, HI (Richardson, 2010). The designs of the bag portion of both prototypes were similar in size and shape, and the volume of both bags was 0.049 m^3 (3000 $in.^3$). The rucksack

prototypes differed in design of the suspension system. Ruck B (Figure 1) had a padded hip belt, and the pack bag was mounted on a frame. The hip belt of Ruck C (Figure 2) was not padded, and Ruck C did not have a frame. The surface of the Ruck C bag closest to the user's back had two vertical cylinders, comprised of fabric and filled with high-density foam, that were placed to create a standoff between the rucksack and the user's back. The design concept was that the cylinders would prevent the rucksack from lying directly on the IOTV, possibly pressing the ESAPI plate into the user's back and causing pain and discomfort.

Figure 1. Ruck B prototype: (A) front, (B) profile, (C) rear.

Figure 2. Ruck C prototype: (A) front, (B) profile, (C) rear.

The three load conditions tested were:

- No Ruck
- Ruck B
- Ruck C

The "No Ruck" condition consisted of the fighting load without a rucksack. Each of the other conditions consisted of the fighting load plus the respective rucksack prototype loaded with Soldier gear to obtain a total weight of 23 kg (50.7 lb), including all components of the rucksack and the load in it. The weight of each load condition is listed in Table 2. The weights include everything that was worn or carried on the body to comprise the condition (i.e., skin-out weight). A Soldier outfitted in the IOTV, the TAP, and the other components of the fighting load and wearing a rucksack is pictured in Figures 3 and 4 (Ruck B and Ruck C, respectively).

Table 2. *Total Weight of Load Conditions*

Load Condition	Weight (lb)	Weight (kg)
No Ruck	38	17
Ruck B	88	40
Ruck C	88	40

Figure 3. Ruck B load configuration.

Figure 4. Ruck C load configuration.

The COM and the MOI were obtained for each rucksack according to the methods employed by Norton et al. (2003). Force and moment data were measured and collected using a force plate (Model OR6-5, AMTI, Watertown, MA, USA) interfaced with a computer-based acquisition system. The reference axes origin selected for taking COM measurements was the bottom, right, anterior corner of each rucksack (i.e., the bottom corner closest to the load-carrier's back and on the right side of the body). An MOI instrument (Model XR250, Space Electronics, Inc., Berlin, CT, USA) was used to determine the MOI of each rucksack. The x, y, and z axes passing through the COM of the rucksack were chosen as the coordinate axes for the measurement, where x is the anterior-posterior axis, y is the medial-lateral axis, and z is the longitudinal axis. It was assumed that the chosen axes corresponded to the principal axes of inertia and the products of inertia were not obtained.

The COM and MOI data for the rucksack prototypes are presented in Table 3. The COM values indicate that Rucks B and C were highly similar, differing by 1.6 cm or less. However, Ruck C had higher MOI values overall than did Ruck B. Ruck C also had a well-defined intermediate MOI about the z axis, I_{zz}, but Ruck B did not (Greenwood, 1965).

Table 3. *Rucksack COM and MOI Values*

	COM (m) Relative to Reference Point on Rucksack			MOI ($kg \cdot m^2$) Relative to Rucksack COM		
Ruck	x	y	z	I_{xx}	I_{yy}	I_{zz}
B	0.1242	0.1190	0.2054	0.4843	0.3472	0.3384
C	0.1079	0.1222	0.1972	0.8317	0.3620	0.6143

Procedure

Testing was conducted at the Center for Military Biomechanics Research, NSRDEC, and at NSRDEC's Soldier Performance Course in Hudson, MA. Volunteers attended 10 sessions of 2.5 to 4 h each, depending on study activities scheduled for that session. Volunteers may have completed more than one of the test activities at a single session. Similarly, there may have been practice on one activity and testing on another within a session. The activities carried out by volunteers during the study, as well as the principal measures taken in conjunction with the activities, were:

- Energy usage and biomechanical responses during treadmill walking at a speed of $1.34\ m \cdot s^{-1}$ for 10 min on 0% and 9% grades
- Biomechanical responses during treadmill running at a speed of $2.24\ m \cdot s^{-1}$ for 10 min on 0% grade
- 30-m rush completion times
- Repetitive box lift and carry cycles completed in 5 min
- Combined obstacle and MOUT course traversal times
- ROM and human factors assessment
- Subjective assessment

Each volunteer was tested under each of the three load conditions. The order in which volunteers were exposed to the conditions was determined by establishing testing sequences for each activity prior to the beginning of the study. The sequences were the six possible permutations of the three load conditions. A sequence was selected at random, without replacement, and a volunteer was assigned to it. This continued until the six permutations had been assigned to six volunteers. For the remaining two volunteers, two sequences were selected at random, without replacement, from the six possible permutations, and one volunteer was assigned to each of the permutations. This procedure was followed for each study activity to establish the order in which volunteers would be exposed to the load conditions.

The methods employed in the study for carrying out each of the test activities are described in the following subsections.

Physiological and Biomechanical Analyses of Treadmill Walking and Biomechanical Analysis of Treadmill Running

Equipment and Measurements

Metabolic measurements. $\dot{V}O_2$ was measured during treadmill walking using the K4b^2 portable metabolic analysis apparatus (COSMED, Rome, Italy), which monitors oxygen uptake and analyzes the expired air. This apparatus measures gas exchange on a breath-by-breath basis. It includes a portable unit that contains the O_2 and CO_2 analyzers, sampling pump, UHF transmitter, barometric sensors, and electronics. There is also a telemetry data transmission receiver unit that consists of a small unit connected to a PC through the RS 232 serial port. A miniaturized transmitter module located inside the portable unit transmits the data. The user wears a mask, which covers the oronasal area and has two inspiratory valves applied for reducing inspiratory resistance and to dry moisture produced during the effort (Figure 5). A bi-directional digital turbine that ensures accuracy within a wide flow range measures flow and volume.

Figure 5. Soldier wearing the K4b^2 portable metabolic analysis apparatus used for measuring oxygen consumption.

The $\dot{V}O_2$, as recorded with the K4b^2 unit, was expressed in absolute terms (ml·min^{-1}). For analysis purposes, $\dot{V}O_2$ was scaled to the volunteer's body mass (ml·kg^{-1}·min^{-1}) and to the total of the volunteer's body mass plus the mass of all items worn or carried on the body (ml·kg^{-1}·min^{-1}). By adjusting the $\dot{V}O_2$ data for each volunteer's body mass, the measure obtained reflected the energy usage attributable to the external load being borne on the body. The external load consisted of clothing, body armor, the other components of a fighting load, and, for two of the conditions tested, a rucksack. Scaling the $\dot{V}O_2$ data for each volunteer's body mass, plus the mass of all items being worn or carried, yielded a measure of the energy used that was not attributable to body mass or to the mass of the external load on the body. Examination of this measure was a means of assessing whether the designs, inertial properties, or some other elements of the rucksacks differed to the extent that one rucksack imposed a greater energy usage burden on the load carrier than the other.

The heart rates of the volunteers were monitored using a Polar Vantage heart rate monitor that is integrated with the K4b^2 system. This heart rate system consists of the main unit of the K4b^2 and a chest strap. The chest strap contains a transmitter that senses heart rate and sends information about heart rate to the K4b^2 unit and software. The heart rate is then interfaced with the computer software and information is stored for later analysis.

Force plate treadmill. For testing during treadmill walking and running, a force plate treadmill fabricated by AMTI (Watertown, MA, USA), was used (Figure 6). This treadmill is comprised of two synchronized side-by-side belts located on a single platform. The treadmill belts are very close together, with a gap of less than 10 mm. The motors for the treadmill belts are synchronized and feedback controlled so that, if the speed of one belt changes, the other belt maintains an identical speed. The treadmill can attain speeds of up to 5.28 m·s^{-1} and can be set at grades of ± 25%. Each belt is mounted over a force plate, which is capable of measuring GRF in three planes. Each force plate in the treadmill provides six continuous voltage output signals corresponding to forces and torques in three orthogonal directions (x, y, z). For this study, the voltage outputs of the force plates were sampled at the rate of 1200 Hz, filtered with a low-pass Butterworth filter (cut-off frequency of 10 Hz), and converted to physical units (N) using manufacturer-supplied calibration factors. The digital values were stored in computer data files.

A number of kinetic variables were derived from the volunteers' force-time histories outputted from the force plate treadmill during walking and running, and the effects of the load conditions on these variables were determined. In analyzing locomotion, GRF is generally decomposed into three orthogonal components. The directions of the components are at right angles to each other: vertical, anterior-posterior, and medial-lateral. By convention (Nigg, 1986), the vertical force is positive; the positive direction is upward, indicating that the force is exerted by the ground on the foot. The anterior-posterior component is commonly referred to as the braking-propulsive component. It is the horizontal force exerted by the ground on the foot in the direction opposite locomotion (braking) or in the same direction as locomotion (propulsive). By convention (Nigg, 1986), braking force is expressed as a negative number and propulsive force as a positive number. The medial-lateral component is horizontal force exerted by the ground on the foot toward or away from the midline of the body. The kinetic variables in this study were calculated from the vertical and the anterior-posterior components of the GRF. The GRF data were expressed as the measured force (N) normalized to the volunteer's body mass (N·kg^{-1}) and

to the volunteer's total mass ($N \cdot kg^{-1}$). Total mass was calculated as body mass plus the mass of all items worn or carried on the body.

Figure 6. Soldier walking up a 9% grade on the force plate treadmill while oxygen consumption, kinematics, and kinetics were being captured.

The patterns of force-time histories of walking strides differ among individuals. However, typical patterns associated with walking are graphed in Figure 7 for each component of the GRF. The abscissa in the graphs is percentage of stance time. Stance time is the elapsed time from initial contact of one foot with the ground until that same foot leaves the ground. The vertical GRF component for walking shows two peaks, as illustrated in Figure 7. The load response peak force occurs early in the stride cycle, at initial contact of the foot with the ground, and the thrust peak force occurs later in the stride cycle, when the foot is pushing off from the ground. The mid-stance period of the gait cycle occurs between the load response and the thrust peaks. The anterior-posterior component also tends to have two peaks, a braking peak during the initial phase of ground contact and a propulsive peak during the later phase (Figure 7). The walking data in this study were analyzed for peak vertical forces at foot contact and at push off and peak braking and propulsive forces.

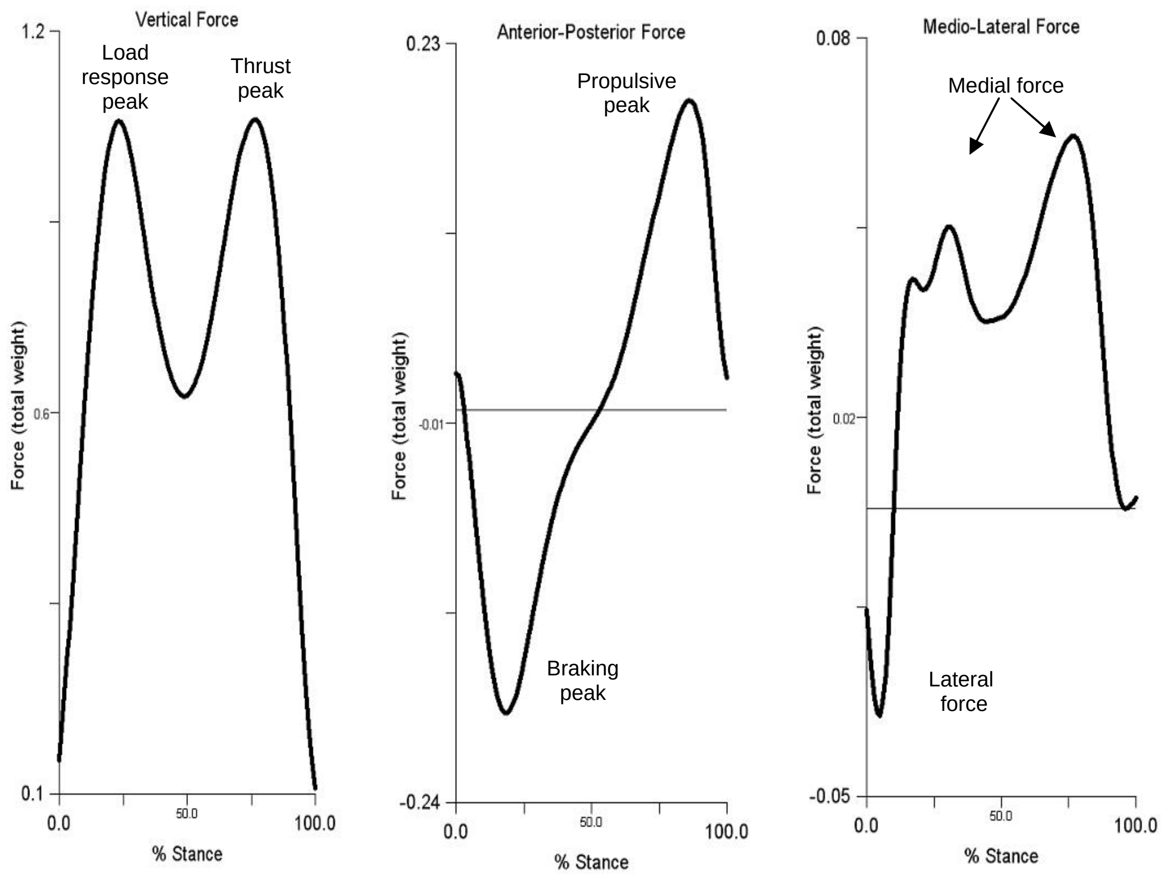

Figure 7. Examples of GRF components during the stance phase of walking. Vertical and anterior-posterior GRF parameters were analyzed in this study.

As in walking, the patterns of force-time histories of running strides differ among individuals. Individuals who make initial contact with their heels (heel-strike runners) show a characteristic configuration of the vertical GRF component. There is an impact peak associated with initial contact of the foot with the ground and a thrust peak associated with push off from the ground. The first peak in the vertical force component of a running stride is characterized by a rapid onset and a relatively large force. In the current data set, not all volunteers displayed the impact peak that is typical of heel-strike running. The reason for this is not known. It could be that the external load added to the body caused some volunteers to display a midfoot landing. Also, volunteers tended to display a shuffling gait, as opposed to a typical running gait, possibly due to the combination of the added load and the relatively slow running speed (2.24 $m \cdot s^{-1}$). Like the vertical force component, the anterior-posterior GRF component for running tends to be biphasic. It has a negative braking peak during the initial phase of ground contact and a positive propulsive peak during the later phase. However, the braking pattern is variable across individuals. In this study, volunteers exhibited one, two, or even more braking peaks. The GRF variables analyzed here for running were peak vertical force, peak braking force (the overall maximum braking force), and peak propulsive force.

GRF is a distributed force that acts over the entire surface of the foot or the shoe that is in contact with the ground. Although GRF does not reveal the magnitude of the forces within the

skeleton during ground contact, examination of the components of the GRF does give some insight into the forces that the total body is exposed to every time the foot contacts and subsequently pushes off from the ground during walking and running. In this study, the GRF variables selected for analysis were those that capture the highest magnitude forces during ground contact and, therefore, those of greatest interest in assessing differences in the load conditions tested.

Motion capture equipment. As the volunteers walked or ran on the treadmill, three-dimensional (3D) motion was recorded by Oqus cameras (Qualisys AB, Gothenburg, Sweden). These data were used to analyze gait kinematics. Retro-reflective markers, about 12 mm in diameter, were placed at selected locations on the volunteer's skin and clothing to expedite processing of the gait kinematics (Figure 6). To capture the volunteer's movements on the treadmill, eight cameras, operating at 120 Hz, were focused on the area of the treadmill. The cameras were positioned on each side of and anterior and posterior to the viewing area. This allowed the kinematics of the whole body to be defined in 3D space with 6 degrees of freedom biomechanical movement analysis for each body segment. The outputs of the cameras and the force plates were collected through a single data acquisition system and were time-synchronized.

The recorded images were processed using dedicated hardware and software (Qualisys AB, Gothenburg, Sweden) to produce files containing time histories of the 3D coordinates of each reflective marker. The Visual3D™ software program (C-motion, Inc., Germantown, MD, USA) was used to process the data files to obtain a number of kinematic variables describing the spatial and temporal characteristics of the volunteer's gait. The gait variables that were calculated in the present study are listed and defined in Table 4. They were analyzed to determine the extent to which gait parameters were affected by the load conditions. As indicated in Table 4, stance time, swing time, and double support time for a stride were expressed as percentages of time to complete the stride.

Testing

For walking trials, the force plate treadmill was set at a speed of 1.34 $m \cdot s^{-1}$ and either a 0% grade or a 9% grade. For running, the treadmill speed was 2.24 $m \cdot s^{-1}$, and the grade was 0%. Prior to the days of formal testing, volunteers were familiarized with walking and running on the force plate treadmill. They walked at test speed at each grade in each of the three load conditions for 2.5 min and then ran at 2.24 $m \cdot s^{-1}$ and 0% grade for about 2.5 min in each load condition. During familiarization and during testing, the volunteers carried the simulated M4 carbine in both hands in front of the body (i.e., the "ready" position).

Each volunteer had 3 days of formal testing. The first day consisted of trials of walking at 1.34 $m \cdot s^{-1}$ and a 0% grade. The next day was walking at 9% grade and 1.34 $m \cdot s^{-1}$. On the third day, the volunteer ran at 2.24 $m \cdot s^{-1}$ and 0% grade. On each of the days, a volunteer participated in three, 10-min trials, with a different load condition being tested during each trial. The volunteer walked or ran continuously throughout the 10-min period. There was a rest of at least 15 min between trials.

Table 4. *Definition of Gait Variables*

Variable	Definition
Stride length (m)	The distance from the point of initial contact of one foot with the ground to the point of the next contact of the same foot with the ground.
Stride time (s)	The time from the initial contact of one foot with the ground until the same foot again contacts the ground. Stride time is also commonly referred to as cycle time.
Stride width (m)	The medial-lateral distance between the right and the left heels as measured at the time of initial ground contact of each foot.
Step time (s)	The time from the initial contact of one foot with the ground until the initial contact of the other foot.
Stance duration (% stride time)	The time from the initial contact of one foot with the ground until the same foot leaves the ground. It is expressed here as a percentage of stride time.
Swing duration (% stride time)	The time from one foot leaving the ground until the same foot contacts the ground. It is expressed here as a percentage of stride time.
Double support duration (% stride time)	The time that both feet are in contact with the ground. It is expressed here as a percentage of stride time. Walking has double support phases; running does not.

During a walking or a running trial, force plate and motion capture camera outputs were recorded simultaneously for 2 min after the trial was underway for at least 3 min. Ten strides, five initiated with a right foot contact and five with a left foot contact, were selected for subsequent analysis from the recorded motion data and GRF data. To obtain the kinematic and the kinetic data for analysis, each dependent measure was calculated for each stride and a mean was obtained over the 10 strides for each measure.

The volunteer wore the mask of the $K4b^2$ metabolic analysis apparatus throughout the walking trial. The data used in subsequent analyses were the $\dot{V}O_2$ measurements made for 90 s beginning at approximately 7 min into a walking trial. The $\dot{V}O_2$ measurements were averaged over 20-s increments for the 90-s gas collection period. These data were then ensemble-averaged for the 90-s period to obtain the absolute value of $\dot{V}O_2$ ($ml \cdot min^{-1}$). To obtain the data for analysis, this value was scaled to the body mass of the participant ($ml \cdot kg^{-1} \cdot min^{-1}$) and to total mass ($ml \cdot kg^{-1} \cdot min^{-1}$). $\dot{V}O_2$ was not recorded during running in order to avoid discomfort that the volunteers might have experienced from the mask of the metabolic measurement apparatus, which covered the nose and the mouth.

Maximal Performance Tests

30-m Rush

Equipment and measurements. Two timing gates were placed 30 m apart and a padded gym mat was placed on the floor immediately beyond each timing gate. The activity started with a volunteer in a prone position on one mat, facing the opposing mat and holding an M4 carbine

in an aiming position (Figure 8). On the volunteer's own mark, he got up and ran forward, triggering the timing gate to start recording. The volunteer ran 30 m at maximal effort past the next timing gate, assumed a prone position on the second mat, and aimed his weapon at a target on a wall beyond the mat. Once locked on the target, the volunteer said "set" and, while still in the prone position, turned 180° to face in the direction of the starting position and said "set" again. Next, the volunteer rose to a standing position and proceeded in the same manner back to the starting position, rushing for 30 m at maximal effort. This cycle was repeated until five 30-m rushes were completed. For scoring, the times to complete each of the five individual run segments and each of the four prone transitions were recorded, along with the total time to complete all five rushes.

Figure 8. Soldier in the prone starting position, about to begin a 30-m rush.

Testing. Volunteers participated in one trial (i.e., five rushes) under each of the three load conditions while carrying the mock M4 carbine. They were encouraged to complete each rush and transition with maximal effort. A volunteer completed all three trials on this test in one day, with a rest break of approximately 20 min between trials. On a day preceding testing, volunteers were familiarized with this activity by performing two to three rushes as quickly as possible while wearing each load condition. On the day of testing, the volunteers were allowed to warm up under each load condition by performing two to three rushes at approximately 50% effort. Times on these preliminary rushes were not recorded.

Repetitive Box Lift and Carry

Equipment and measurements. This activity entailed lifting a metal box by its handles from floor level, carrying it, and placing it on a shelf at a height simulating the height of an Army 5-ton truck bed (Figure 9). The box was approximately 38 cm wide, 11 cm deep, and

23 cm high. There were two handles on opposing sides of the box. For this study, the box was weighted to 20.5 kg. The box was at the end of a smooth ramp, at floor level, 3.05 m away from and directly in front of a wooden platform. The height of the platform from the floor was 1.32 m. The path from the box to the platform was a straight path without obstructions. The number of boxes carried to the platform each minute and the total number carried over 5 min were recorded.

Figure 9. Soldier carrying a weighted box toward the platform while executing the repetitive box lift and carry test.

Testing. A trial of this activity consisted of lifting the box from the floor, carrying it to the platform, placing it on the platform, and returning to the starting position to lift another box from the floor. This process was repeated as many times as possible within a 5-min period. Volunteers were encouraged to complete as many cycles of this task as they could within the allotted time. The M4 carbine was not carried while the task was being done. The test was performed once under each load condition and each volunteer participated in all three trials in one day, with a rest break of approximately 20 min between trials. On a day preceding testing, volunteers were familiarized with this activity by performing 1 min of box lifts at maximal effort while wearing each load condition. On the day of testing, the volunteers were allowed to warm up under each load condition by performing 1 min of box lifting at approximately 50% of maximal effort.

Combined Obstacle and MOUT Course Traversal

Equipment and measurements. The NSRDEC Soldier Performance Course, located in Hudson, MA, is designed to evaluate Soldiers' agility as affected by Soldier-borne equipment. The course includes an outdoor obstacle portion and an indoor MOUT portion. Both portions of the course were used in this study. The outdoor portion consists of obstacles designed to place Soldiers in a variety of postures while they progress through the course: high fence, log balance, up-and-down ramp, tire run, pipe crawl, high crawl, low crawl, zigzag, and poles on a serpentine path (Figure 10).

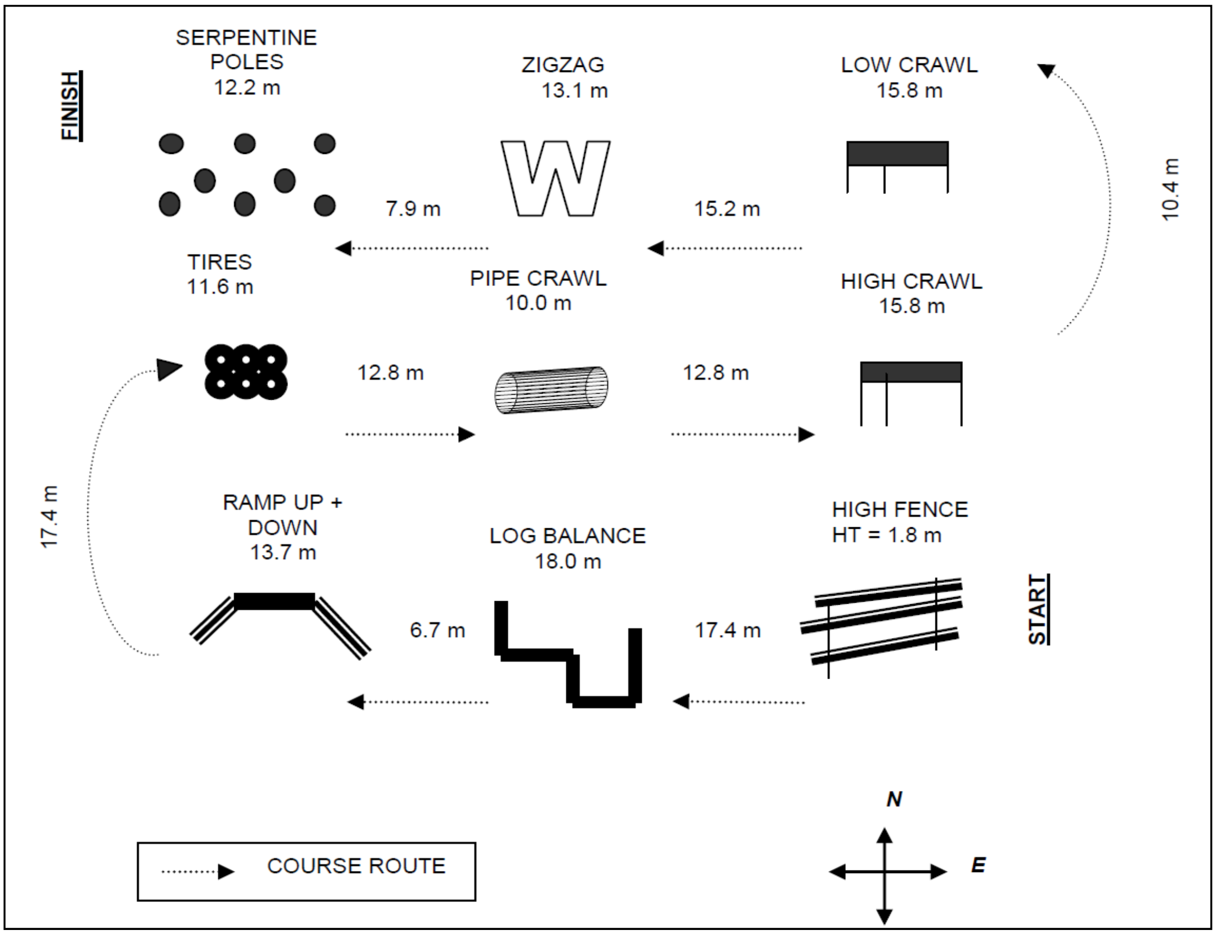

Figure 10. Outdoor obstacle portion of the NSRDEC Soldier Performance Course.

The indoor, MOUT portion of the NSRDEC course is immediately adjacent to the outdoor portion and is laid out in a two-story building to mimic urban environments seen in theater. The course consists of entering the building on the ground level, running diagonally through a room, dashing toward a set of stairs, running up the stairs to the second floor where the Soldier climbs through three windows differing in dimensions, and finishing via the second floor external staircase (Figure 11).

The total time to complete the two portions of the course was recorded, as were times to complete individual obstacles or segments of the course.

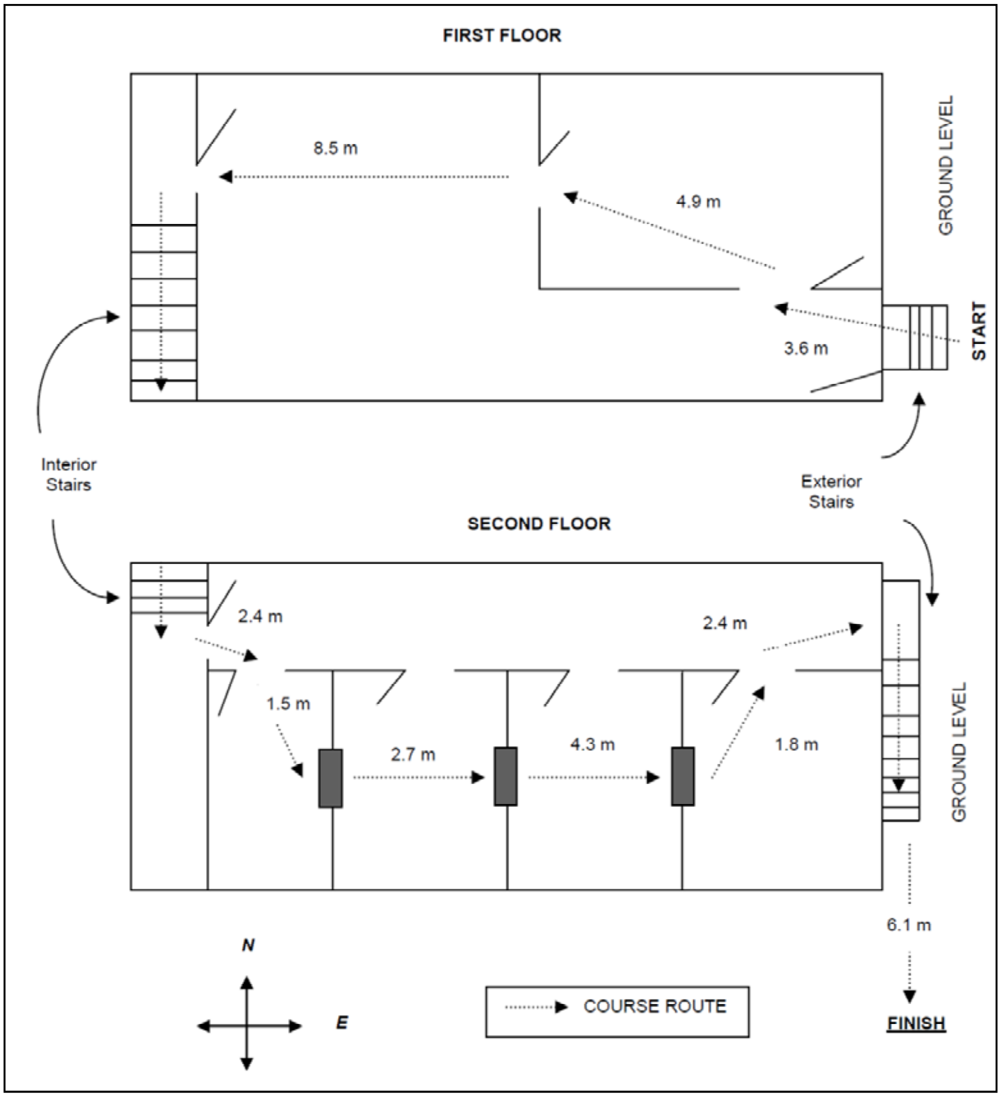

Figure 11. Indoor MOUT portion of the NSRDEC Soldier Performance Course.

Testing. For this study, one run of the course consisted of a volunteer completing the outdoor obstacle portion (Figure 10) and immediately undertaking the indoor MOUT portion (Figure 11). Each volunteer ran the course once under each of the three load conditions. The volunteers participated in all three trials on one day, with a rest break of approximately 35 min between trials. The simulated M4 carbine was carried on the course runs. On a day preceding testing, the volunteers were familiarized with this activity by performing one course run-through while wearing each load condition (Figure 12). On the day of testing, the volunteers were allowed to warm up under each load condition by performing one course run-through at approximately 50% effort.

Figure 12. Soldier traversing the log balance obstacle at the NSRDEC Soldier Performance Course.

Range of Motion Measurement and Human Factors Assessment

During this portion of the study, ROM and ability to perform certain movements were assessed for all three load conditions. The activities comprising this portion of the study are described here.

Range of Motion

The volunteers executed a series of simple body mobility tasks. They were given three successive trials on each mobility task in each load condition. The maximum extent of movement possible was measured by using either a meter stick or a gravity goniometer (Glanville & Kreezer, 1937; Leighton, 1942). A goniometer measures the angular displacement at a body joint (e.g., elbow, shoulder, knee). The score on a mobility task was the mean of the

three trials under a given load condition. The simulated M4 carbine was not used during this testing. The movements, listed in the order in which they were performed, were as follows:

- Walk Forward Five Steps: The volunteer took five steps forward, each as far forward as possible. The distance from the heel of the foot when starting to the toe of the foot upon taking the fifth step was measured and recorded.
- Standing Trunk Flexion: The volunteer was asked to attempt to touch the floor at a point just in front of his feet while keeping his knees straight. The distance between his fingertips and the floor was measured. A score of “0” was assigned if he touched the floor.
- Upper Arm Abduction: Maintaining the body in an upright posture and starting with the arms at the sides, the volunteer raised both arms sideward and upward as far as possible. The movement from the starting position was measured with a goniometer.
- Shoulder Flexion With Elbow Extended: Maintaining the body in an upright posture and starting with the arms at the sides, the volunteer raised the right arm forward and up as far as possible while keeping the elbow straight. The movement from the starting position was measured with a goniometer.
- Hip Flexion With Knee Extended: Holding the back of a chair for support, the volunteer raised the leg as far forward and up as possible while keeping the knee straight. A goniometer was used to measure the amount of flexion.
- Hip Flexion With Knee Bent: Allowing the knee to bend freely, the volunteer raised the upper leg as far up as possible. The volunteer grasped a support (the back of a chair) while raising the leg. The amount of flexion was measured with a goniometer.
- Kneel and Rise: The volunteer was rated on ability to rise from a kneeling position, either with or without assistance. He began in a standing position, got down on both knees, and stood up again. The rating scale was: 0 = cannot get down on both knees; 1 = cannot rise from kneeling position without help from investigator; 2 = can rise from kneeling position, but needs to grasp object for support; 3 = can rise from kneeling position without any help at all.

Movements

The volunteers executed a number of movements once under each load condition. The movements, which are commonly performed by military personnel, were as follows:

- Prone (Unsupported) Firing Position: The volunteer assumed a prone firing position, unsupported, and the ability to cheek and sight a mock M4 carbine was documented.
- Kneeling (Unsupported) Firing Position: The volunteer assumed a kneeling firing position, unsupported, and the ability to cheek and sight a mock M4 carbine was documented.
- Standing (Unsupported) Firing Position: The volunteer assumed a standing firing position, unsupported, and the ability to cheek and sight a mock M4 carbine was documented.
- Squatting: The volunteer attempted to squat down with legs placed approximately a shoulder width apart and then to rise. The ability to do so and the ease with which it was

done were recorded. Any requirements for an investigator's assistance or for a stationary support were noted.

- Donning and Doffing: The volunteer donned and doffed the components of each load condition. This was to be done without assistance. The ability to complete the action, as well as the ease of doing so, was recorded. Any requirements for an investigator's assistance or difficulty adjusting or securing a component were noted.

Human Factors Issues

Throughout the study, the investigators observed whether there were any problems that could cause injury to the Soldier or be detrimental to the mission. In addition, the investigators looked for other human factors issues that were related to ease of use of the components of each load condition and their compatibility with other military equipment. These included any difficulties the volunteers encountered when donning and adjusting the equipment and any displacement of equipment components on the body when volunteers were carrying out physical activities.

Subjective Assessment

Information was acquired from the volunteers upon completion of selected study activities regarding the particular load condition being tested. The 15-category Borg (1970) rating of perceived exertion (RPE) scale for rating perceived exertion from *no exertion at all* (rest) to *maximal exertion* was used (Appendix A). The RPE was administered at the end of each 10-min bout of treadmill walking and of treadmill running, upon completion of the five 30-m rushes and the 5-min trials of the box lift and carry task, and at the end of each traversal of the combined obstacle and MOUT course.

The rating of pain, soreness, and discomfort (RPSD) questionnaire (Corlett & Bishop, 1976) was also administered to the volunteers at a number of points in the study to obtain their opinions regarding the rucksacks under test. In the RPSD questionnaire, the respondent used a 5-point scale to rate the level of pain, soreness, discomfort, or restriction being experienced at specific parts of the body (Appendix B). Study-specific questionnaires were devised as well to obtain volunteers' opinions regarding the rucksacks under test. These questionnaires were administered principally during the human factors assessment portion of the study.

Statistical Analysis

The physiological, biomechanical, and maximal performance data, as well as the RPE data, were analyzed using SPSS 14.0 (SPSS, Inc., Chicago, IL, USA). The dependent measures were subjected to one-way, repeated measures analyses of variance (ANOVAs) to assess the differences among the three load conditions (No Ruck, Ruck B, and Ruck C) with $\alpha = .05$. Mauchly's test of sphericity was used. For sets of data that did not meet the sphericity assumption, the Greenhouse-Geisser adjustment was applied to the degrees of freedom. Post hoc tests in the form of t tests were carried out on main effects found to be statistically significant. The significance level for the post hoc tests was set at $p < .05$. The Bonferroni method was used to make adjustments for multiple comparisons.

A number of items on the study-specific questionnaires required that volunteers indicate their selections using rating scales or yes/no response alternatives, and the data for a question consisted of frequencies in discrete categories (e.g., rucksack easy/not easy to adjust). The response data for rating scales were summarized by computing a median. The questionnaire items were analyzed using nonparametric statistical tests, mainly in the form of chi-square (χ^2) tests for homogeneity of proportions in related samples (Marascuilo & McSweeney, 1985; Siegel & Castellan, 1988). The significance level was set at $p < .05$. Post hoc analyses were done if the main test achieved significance.

RESULTS

The results are presented here of the analyses carried out to assess the effects of the three load conditions (No Ruck, Ruck B, and Ruck C) on the dependent measures for energy usage during walking and the biomechanics of walking and running. The data for measures taken to quantify performance on the 30-m rush, the repetitive box lift and carry, and the combined obstacle and MOUT course traversal are also presented. The results are included as well for the ROM measurements, the activities carried out as part of the human factors assessment of the rucksacks, and the subjective measures used in the study.

Most of the figures and the tables presented here contain results of post hoc statistical difference tests. Results of the tests are indicated by upper case letters (e.g., X, Y, and Z). Load conditions that do not share the same letter differed significantly in post hoc tests ($p < .05$). Conversely, those conditions that share the same letter were not significantly different ($p > .05$). Using Figure 13 as an example of this scheme, at both the 0% and the 9% walking grades, the letter “Y” is associated with the Ruck B and the Ruck C conditions, whereas the letter “X” is associated with the No Ruck condition. These designations indicate that there were no significant differences in the data for Rucks B and C and that the data for both rucksack conditions differed significantly from the data for the No Ruck condition.

There were instances during testing in which data were obtained on only seven of the eight volunteers because personal business prevented a volunteer from participating in a testing session and rescheduling the session was not feasible. All volunteers who participated in a given test activity were able to complete the testing protocol successfully under each of the load conditions. The number of volunteers contributing to a dataset is indicated in the figures and the tables.

Energy Usage When Walking

$\dot{V}O_2$ was the measure of the energy used wearing the load conditions while walking at $1.34\ m\cdot s^{-1}$ on 0% and 9% grades. The data were expressed as $\dot{V}O_2$ scaled to the volunteer’s body mass, in $ml\cdot kg^{-1}\cdot min^{-1}$, and as $\dot{V}O_2$ scaled to total mass (body mass plus the mass of all clothing and other items being worn or carried), in $ml\cdot kg^{-1}\cdot min^{-1}$. The two forms of $\dot{V}O_2$ data were analyzed separately, and the data for the 0% and the 9% grades were also analyzed separately. The results of the analyses are presented here, along with means and standard errors of the mean (*SEM*) for the load conditions.

Energy Usage Scaled to Body Mass

The ANOVAs performed on the data for $\dot{V}O_2$ scaled to body mass for walking at the 0% and the 9% grades both yielded a significant main effect of load condition. The post hoc tests for the two grades revealed similar relationships among the loads: energy usage was significantly lower with the No Ruck condition than with the Ruck B or the Ruck C conditions, and the two rucksack conditions did not differ significantly from each other. The means of $\dot{V}O_2$ scaled to body mass for walking at the 0% and the 9% grades are presented in Figure 13, along with the

results of the post hoc tests. Analyses were not performed to contrast the two grades, but it can be seen in Figure 13 that $\dot{V}O_2$ was substantially higher at the 9% than at the 0% grade.

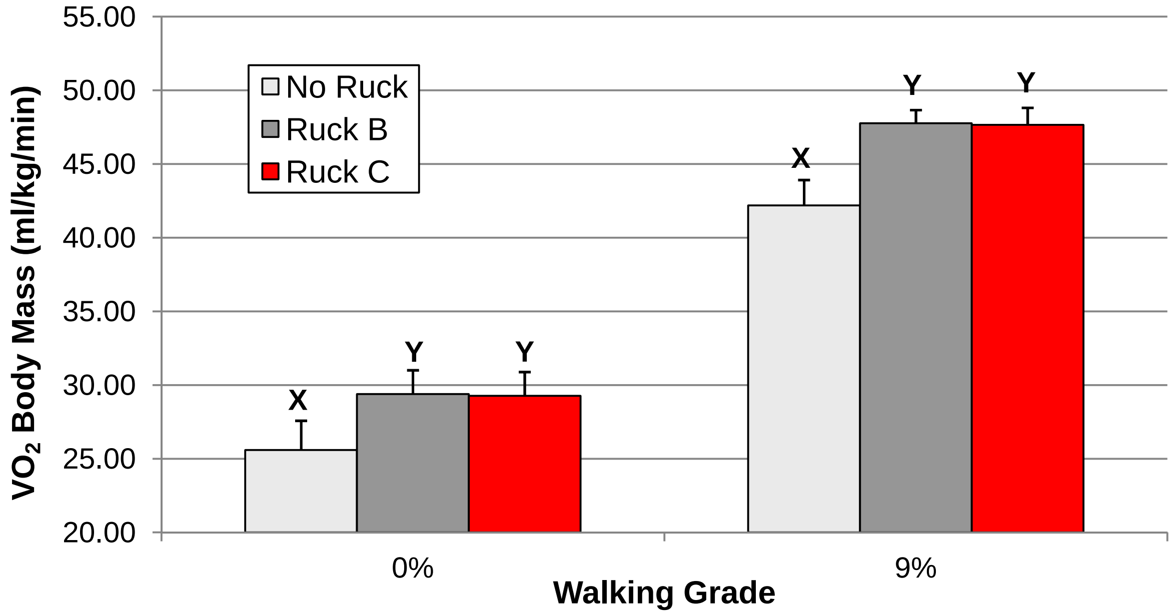

Figure 13. Mean (+1 *SEM*) $\dot{V}O_2$ scaled to body mass for each load condition during walking at 1.34 $m \cdot s^{-1}$ on 0% and 9% grades. At each grade, load conditions that do not share the same letter differed significantly in post hoc tests ($p < .05$; $N = 8$).

Energy Usage Scaled to Total Mass

The means for $\dot{V}O_2$ scaled to total mass for walking at the 0% and the 9% grades are presented in Figure 14. Analysis of $\dot{V}O_2$ scaled to total mass for walking at the 0% grade revealed a significant main effect of load condition. However, after correcting the post hoc tests for multiple comparisons, no significant differences were obtained among the load conditions. For the 9% grade walking data, a significant main effect of load condition on $\dot{V}O_2$ scaled to total mass was also obtained. In this case, post hoc tests indicated that $\dot{V}O_2$ scaled to total mass was significantly higher for the No Ruck condition compared with the Ruck B and the Ruck C conditions, which did not differ significantly from each other. The data in Figure 14 indicate that, although the No Ruck condition did not differ significantly from the Ruck B or the Ruck C conditions at 0% grade, the mean $\dot{V}O_2$ value for the No Ruck condition was somewhat higher than the mean values for Rucks B and C, which were very similar to each other. The two grades were not contrasted in a statistical analysis. However, as was found for $\dot{V}O_2$ scaled to body mass, the mean values for $\dot{V}O_2$ scaled to total mass were substantially higher for the 9% than for the 0% grade (Figure 14).

Biomechanical Analysis of Treadmill Walking and Running

Variables calculated from the motion-time histories and the ground reaction force-time histories recorded during walking at 1.34 $m \cdot s^{-1}$ on 0% and 9% grades and running at 2.24 $m \cdot s^{-1}$ on a 0% grade were analyzed to examine the effects of load condition on gait biomechanics. The

walking data at each grade and the running data were subjected to separate ANOVAs. The findings are presented here.

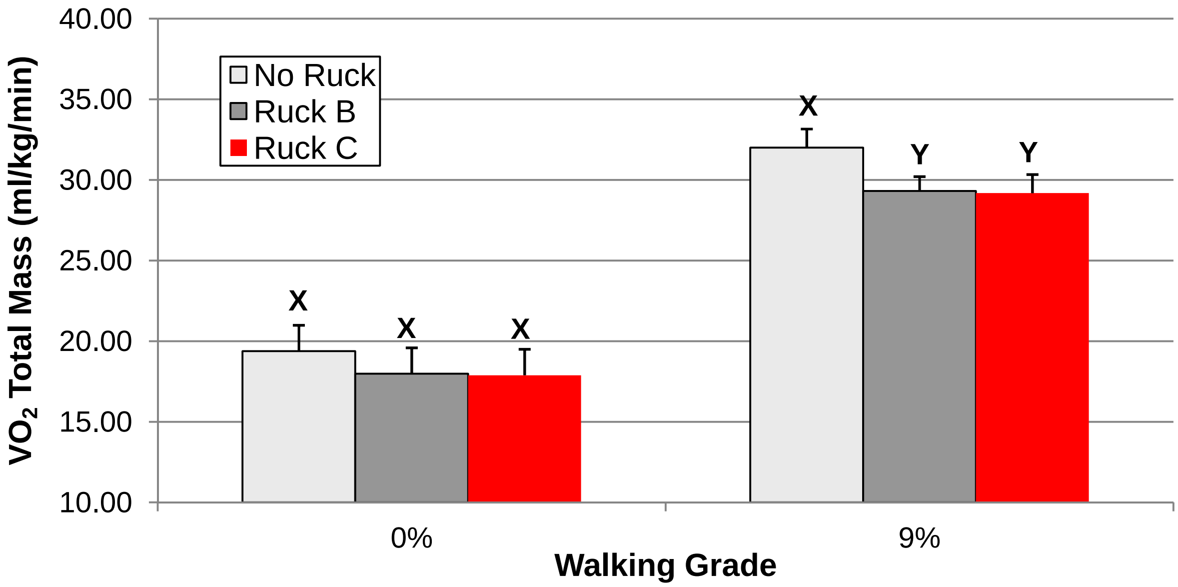

Figure 14. Mean (+1 *SEM*) $\dot{V}O_2$ scaled to total mass for each load condition during walking at 1.34 $m \cdot s^{-1}$ on 0% and 9% grades. At each grade, load conditions that do not share the same letter differed significantly in post hoc tests ($p < .05$; $N = 8$).

Spatial and Temporal Gait Variables

The spatial and temporal variables calculated from the walking and the running kinematic data are defined in Table 4. The ANOVAs performed on these variables revealed that a number of them were not significantly affected by load condition. These variables were stride length, stride time, stride width, and step time. For completeness, the summary data for these variables are presented here, along with the findings related to the variables that were significantly affected by load condition.

Walking at 0% Grade

In the analyses performed on the spatial and temporal variables for walking at 0% grade, stance, swing, and double support durations, expressed as percentages of stride time, were found to be significantly affected by load condition. The means, *SD*, and post hoc test results for each of these variables are presented in Table 5. For these three variables, the post hoc tests revealed that the No Ruck condition differed significantly from both the Ruck B and the Ruck C conditions; there were no significant differences between the two rucksack conditions. The means indicated that stance and double support durations, expressed as a percentage of stride time, were significantly longer when Ruck B or Ruck C was worn than when a rucksack was not used, whereas swing duration was significantly shorter with a rucksack than without one.

Table 5. *Means (SD) of Spatial and Temporal Gait Variables for Each Load Condition During Walking at 1.34 m·s^{-1} on a 0% Grade (N = 8)*

	Load Condition		
Variable	No Ruck	Ruck B	Ruck C
Stride Length (m)	1.37_X (0.05)	1.38_X (0.05)	1.37_X (0.04)
Stride Time (s)	1.05_X (0.04)	1.06_X (0.04)	1.05_X (0.03)
Stride Width (m)	0.18_X (0.04)	0.19_X (0.04)	0.19_X (0.04)
Step Time (s)	0.53_X (0.02)	0.53_X (0.02)	0.52_X (0.02)
Stance Duration (% stride time)	62.29_X (0.96)	64.11_Y (1.45)	63.80_Y (0.77)
Swing Duration (% stride time)	37.71_X (0.96)	35.89_Y (1.45)	36.20_Y (0.77)
Double Support Duration (% stride time)	24.60_X (1.96)	28.26_Y (2.90)	27.71_Y (1.52)

Note. For each dependent variable, means that do not share the same subscript differed significantly in post hoc tests ($p < .05$).

Walking at 9% Grade

The ANOVAs performed on the walking data for the 9% grade yielded significant main effects of load condition on the same dependent measures that were found to be significant in the ANOVAs carried out on the walking data for the 0% grade. That is, stance, swing, and double support durations, expressed as percentages of stride time, were again significantly affected by load condition. However, after the post hoc tests were corrected for multiple comparisons, none of these measures achieved significance. The summary statistics and post hoc test results for the spatial and temporal gait variable at 9% grade are presented in Table 6.

Running at 0% Grade

In the analyses performed on the spatial and temporal gait variables for running at 0% grade, the dependent measures found to be significantly affected by load condition were the temporal measures of stance and swing durations as percentages of stride time. The summary statistics for these measures and the results of the post hoc tests are presented in Table 7. The measures are defined in Table 4. As was the case for walking at 0% grade, the No Ruck condition was significantly different than Rucks B and C, whereas the two rucksack conditions did not differ significantly. Again in agreement with the walking data for 0% grade, stance duration during running was significantly longer with than without a rucksack and swing time was significantly shorter with a rucksack than when a rucksack was not used (Table 7).

Table 6. *Means (SD) of Spatial and Temporal Gait Variables for Each Load Condition During Walking at 1.34 m·s^{-1} on a 9% Grade (N = 7)*

Variable	Load Condition		
	No Ruck	Ruck B	Ruck C
Stride Length (m)	1.38 $_X$ (0.07)	1.34 $_X$ (0.05)	1.35 $_X$ (0.07)
Stride Time (s)	1.05 $_X$ (0.06)	1.03 $_X$ (0.03)	1.03 $_X$ (0.05)
Stride Width (m)	0.19 $_X$ (0.05)	0.19 $_X$ (0.04)	0.20 $_X$ (0.04)
Step Time (s)	0.53 $_X$ (0.03)	0.52 $_X$ (0.02)	0.51 $_X$ (0.03)
Stance Duration (% stride time)	64.14 $_X$ (2.14)	65.91 $_X$ (1.85)	64.96 $_X$ (2.26)
Swing Duration (% stride time)	35.86 $_X$ (2.14)	34.09 $_X$ (1.85)	35.03 $_X$ (2.23)
Double Support Duration (% stride time)	28.27 $_X$ (4.23)	31.74 $_X$ (3.82)	30.62 $_X$ (2.92)

Note. For each dependent variable, means that share the same subscript did not differ significantly in post hoc tests ($p > .05$).

Table 7. *Means (SD) of Spatial and Temporal Gait Variables for Each Load Condition During Running at 2.24 m·s^{-1} on a 0% Grade (N = 8)*

Variable	Load Condition		
	No Ruck	Ruck B	Ruck C
Stride Length (m)	1.62 $_X$ (0.09)	1.60 $_X$ (0.09)	1.59 $_X$ (0.07)
Stride Time (s)	0.74 $_X$ (0.04)	0.74 $_X$ (0.04)	0.74 $_X$ (0.03)
Stride Width (m)	0.10 $_X$ (0.04)	0.10 $_X$ (0.04)	0.10 $_X$ (0.04)
Step Time (s)	0.37 $_X$ (0.02)	0.37 $_X$ (0.02)	0.37 $_X$ (0.02)
Stance Duration (% stride time)	41.84 $_X$ (2.88)	51.74 $_Y$ (0.90)	50.12 $_Y$ (4.99)
Swing Duration (% stride time)	58.17 $_X$ (2.88)	48.26 $_Y$ (0.90)	49.88 $_Y$ (4.90)

Note. For each dependent variable, means that do not share the same subscript differed significantly in post hoc tests ($p < .05$).

Ground Reaction Force

The variables presented here were calculated from the vertical and the anterior-posterior components of the GRF. Peak forces were obtained from the components. The data for these variables were expressed as the measured force normalized to the volunteer's body mass, in $N \cdot kg^{-1}$, and as the force normalized to total mass (body mass plus the mass of all clothing and equipment items worn), in $N \cdot kg^{-1}$.

Walking at 0% Grade

For walking at 0% grade, the ANOVAs performed on the four GRF measures normalized to body mass each yielded a significant effect of load condition. Summary statistics and results of the post hoc tests done on these measures are presented in Table 8. It can be seen that the post hoc tests revealed similar relationships among the load conditions on all four measures: Rucks B and C were associated with peak forces that were significantly higher than that for the No Ruck condition, whereas the peak forces for the rucksacks did not differ significantly. When the GRF measures normalized to total mass were analyzed, none of the ANOVAs yielded a significant main effect of load condition. The summary statistics for these data are included in Table 8.

Table 8. *Means (SD) of Peak GRFs for Each Load Condition During Walking at 1.34 $m \cdot s^{-1}$ on a 0% Grade (N = 8)*

	Load Condition		
Variable	No Ruck	Ruck B	Ruck C
Force Normalized to Body Mass ($N \cdot kg^{-1}$)			
Load Response	15.25 $_X$ (1.737)	18.25 $_Y$ (2.04)	18.52 $_Y$ (2.21)
Thrust	13.65 $_X$ (1.25)	16.41 $_Y$ (1.24)	16.27 $_Y$ (1.52)
Braking	-2.36 $_X$ (0.26)	-3.11 $_Y$ (0.37)	-3.11 $_Y$ (0.49)
Propulsive	2.70 $_X$ (0.25)	3.31 $_Y$ (0.35)	3.30 $_Y$ (0.25)
Force Normalized to Total Mass ($N \cdot kg^{-1}$)			
Impact	11.50 $_X$ (1.04)	11.10 $_X$ (0.73)	11.24 $_X$ (0.86)
Thrust	10.32 $_X$ (1.00)	10.01 $_X$ (0.69)	9.91 $_X$ (0.86)
Braking	-1.79 $_X$ (0.20)	-1.90 $_X$ (0.23)	-1.89 $_X$ (0.28)
Propulsive	2.04 $_X$ (0.17)	2.02 $_X$ (0.16)	2.01 $_X$ (0.10)

Note. For each dependent variable, means that do not share the same subscript differed significantly in post hoc tests ($p < .05$).

Walking at 9% Grade

The summary statistics and the results of the post hoc tests done on the GRF variables for walking at 9% grade are presented in Table 9. As was the case with the analyses of the peak GRFs for walking at 0% grade, the ANOVAs performed on the four peak GRF measures normalized to body mass for walking at the higher grade each revealed a significant effect of load condition. The post hoc tests for the four variables again indicated that Rucks B and C were associated with peak forces that were significantly higher than that for the No Ruck condition, whereas the peak forces for the two rucksacks did not differ significantly. When the data were normalized to total mass, the ANOVAs for load response peak, peak thrust, and peak braking forces again yielded significant main effects of load condition, but the ANOVA for peak propulsive force did not. After adjusting the post hoc results for multiple comparisons, only peak thrust force normalized to total mass revealed significant differences among load conditions. It was found that peak thrust forces with Rucks B and C were significantly lower than the peak force for the No Ruck condition. The two rucksack conditions did not differ significantly on this measure (Table 9).

Table 9. *Means (SD) of Peak GRFs for Each Load Condition During Walking at 1.34 $m \cdot s^{-1}$ on a 9% Grade (N = 8)*

	Load Condition		
Variable	No Ruck	Ruck B	Ruck C
Force Normalized to Body Mass ($N \cdot kg^{-1}$)			
Load Response	13.82_X (1.02)	17.63_Y (1.56)	18.09_Y (2.04)
Thrust	15.10_X (0.91)	17.41_Y (1.24)	17.32_Y (1.38)
Braking	-2.30_X (0.30)	-3.14_Y (0.50)	-3.13_Y (0.55)
Propulsive	2.32_X (0.29)	3.00_Y (0.33)	3.00_Y (0.33)
Force Normalized to Total Mass ($N \cdot kg^{-1}$)			
Load Response	10.47_X (0.47)	10.77_X (0.38)	11.03_X (0.66)
Thrust	11.45_X (0.54)	10.65_Y (0.48)	10.60_Y (0.74)
Braking	-1.74_X (0.22)	-1.92_X (0.26)	-1.91_X (0.29)
Propulsive	1.75_X (0.19)	1.83_X (0.12)	1.83_X (0.11)

Note. For each dependent variable, means that do not share the same subscript differed significantly in post hoc tests ($p < .05$).

Running at 0% Grade

Table 10 contains the summary statistics and the results of the post hoc tests for peak vertical, braking, and propulsive forces during running at 0% grade. When the data were normalized to body mass, the ANOVA for each of the three dependent measures revealed a significant effect of load condition. After adjusting the post hoc tests performed on peak braking force for multiple comparisons, no significant differences were obtained among load conditions. For the peak vertical and the peak propulsive forces normalized to body mass, the post hoc tests indicated that force magnitudes with Rucks B and C were significantly higher than that with the No Ruck condition. Analysis of the running GRFs adjusted for total mass yielded significant main effects of load condition on peak vertical and peak braking forces, but not on peak propulsive force. After adjusting the post hoc test results for multiple comparisons, only peak braking force normalized to total mass revealed significant differences in the load conditions. On this measure, mean forces with Rucks B and C were significantly lower than that with the No Ruck condition, and the forces with the two rucksacks did not differ significantly (Table 10).

Table 10. *Means (SD) of Peak GRFs for Each Load Condition During Running at 2.24 $m \cdot s^{-1}$ on a 0% Grade (N = 8)*

	Load Condition		
Variable	No Ruck	Ruck B	Ruck C
Force Normalized to Body Mass ($N \cdot kg^{-1}$)			
Vertical	21.97_X (4.56)	24.94_Y (5.28)	25.18_Y (5.90)
Braking	-2.36_X (0.56)	-2.58_X (0.66)	-2.56_X (0..67)
Propulsive	1.57_X (0.35)	1.90_Y (0.53)	1.87_Y (0.42)
Force Normalized to Total Mass ($N \cdot kg^{-1}$)			
Vertical	18.06_X (1.64)	16.52_X (1.01)	16.49_X (0.87)
Braking	-1.93_X (0.22)	-1.70_Y (0.23)	-1.67_Y (0.24)
Propulsive	1.29_X (0.15)	1.25_X (0.20)	1.24_X (0.16)

Note. For each dependent variable, means that do not share the same subscript differed significantly in post hoc tests ($p < .05$).

Maximal Performance Tests

The performance tests of the 30-m rush, the repetitive box lift and carry, and the combined obstacle and MOUT course traversal were selected for inclusion in this study because these tests are related to activities that Soldiers perform in the field. In addition, each of the tests can be administered in a standardized manner and performance on each test can be readily quantified. It can be argued that Soldiers operating in a field environment would remove their rucksacks before undertaking a repetitive lifting and carrying task. However, there are

undoubtedly situations in which rucksacks must be worn while executing such a task. Further, because body armor is likely to be worn while executing these types of activities, results from the No Ruck condition are important for military performance knowledge. The results for the performance tests are presented here.

30-m Rush

Three separate analyses were carried out on the data for the 30-m rushes to assess the effects of load condition on this task: total time to complete all five rushes, individual times for each of the five successive run portions of the rushes, and individual times for each of the four transitions. The means, *SEM*, and results of the post hoc analysis for total time to complete the five rushes are presented in Figure 15. The ANOVA performed on this measure revealed a significant effect of load condition. The post hoc tests indicated that total rush time with the No Ruck condition was significantly faster than times with Rucks B and C and that total times with the rucksacks did not differ significantly.

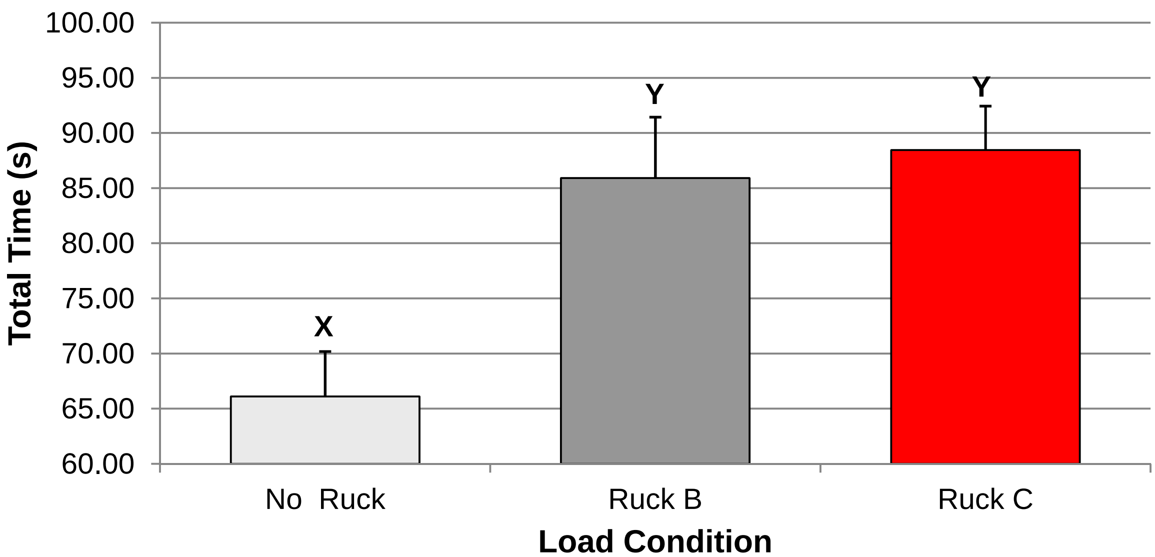

Figure 15. Mean (+1 *SEM*) total time to complete five rushes for each load condition. Load conditions that do not share the same letter differed significantly in post hoc tests (p < .05; N = 8).

For the second analysis of the 30-m rush data, the times for the five run segments of the rushes were analyzed, with the independent variables being load condition and run number. A plot of the data is presented in Figure 16. The interaction between load and run number was not significant. However, the main effects of load and of run number were significant. With regard to load, run times were significantly shorter for the No Ruck condition than for Rucks B or C, which did not differ significantly. For the runs, the shortest completion time was achieved on run 1, followed by run 2. Completion times for runs 1 and 2 differed significantly from each other and from times for runs 3, 4, and 5. There were no significant differences among times for runs 3, 4, and 5.

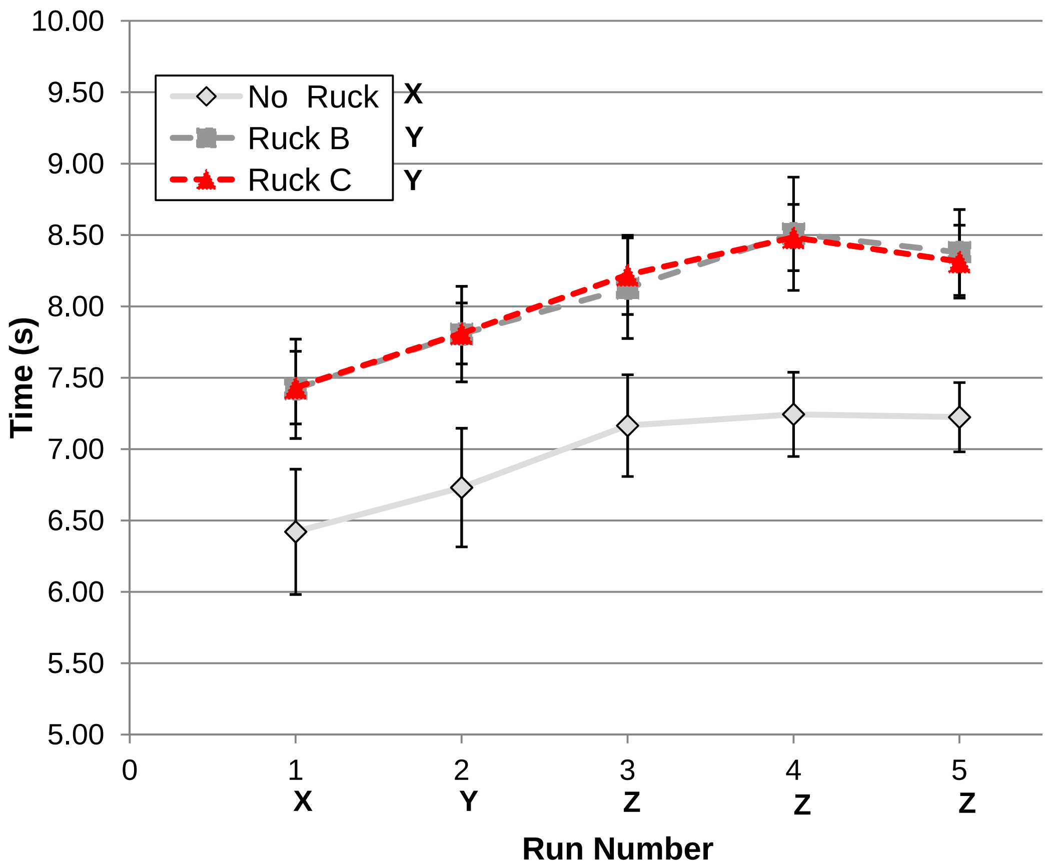

Figure 16. Mean (±1 *SEM*) time to complete each of five runs on the 30-m rush test for each load condition. Load conditions that do not share the same letter and individual runs that do not share the same letter differed significantly in post hoc tests ($p < .05$; $N = 8$).

For the third analysis of the 30-m rush data, the times for the four transition segments were analyzed, along with load condition. A plot of the data is presented in Figure 17. The interaction between transition number and load was not significant, but the main effect of each of these variables was significant. The No Ruck condition yielded significantly shorter transition times than the Ruck B or the Ruck C conditions, which did not differ from each other. For the transitions, times for transition 1 were significantly faster than times for transitions 2, 3, or 4, and these transition times did not differ significantly from each other.

Repetitive Box Lift and Carry

The total number of cycles completed in 5 min on the box lift and carry task was analyzed to assess differences among the load conditions. The total number of cycles was higher for the No Ruck condition than for the Ruck B or the Ruck C conditions. However, the ANOVA did not reveal a significant effect of load condition. The summary statistics and the results of the statistical analysis of the data are presented in Figure 18. A second ANOVA was done in which load condition and time (i.e., minutes 1 through 5) were the independent variables. This ANOVA did not yield significant main effects of load condition or time, and the interaction between these variables was not significant.

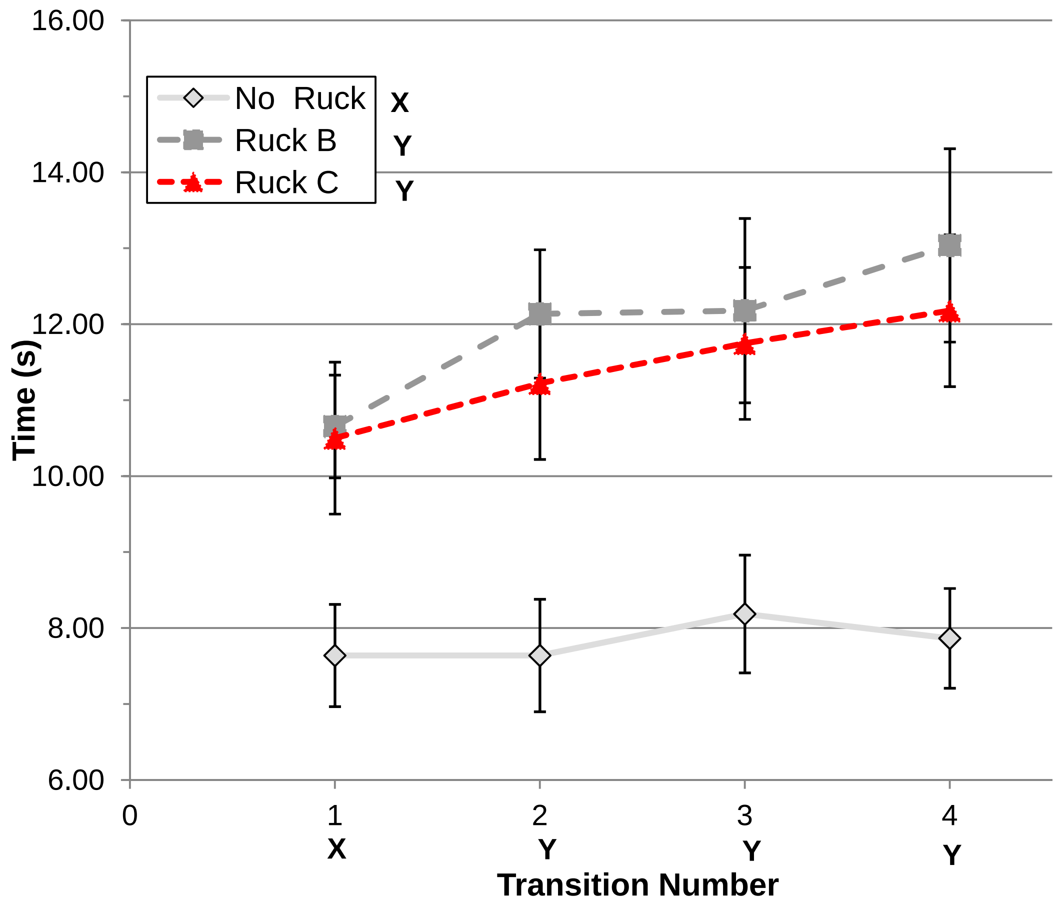

Figure 17. Mean (±1 *SEM*) time to complete each of four transitions on the 30-m rush test for each load condition. Load conditions that do not share the same letter and individual transitions that do not share the same letter differed significantly in post hoc tests ($p < .05$; $N = 8$).

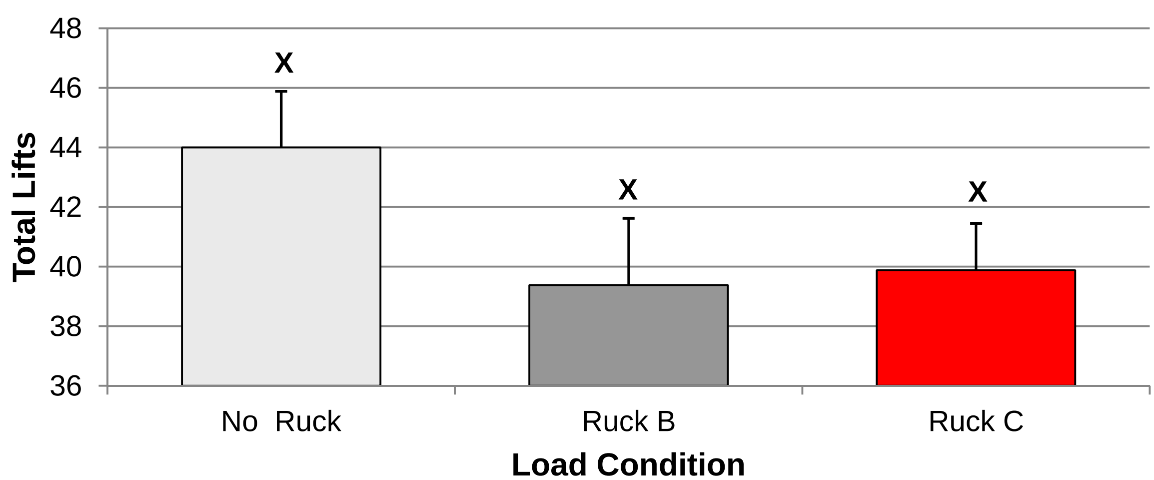

Figure 18. Mean (+1 *SEM*) box lifts completed in 5 min for each load condition. Load conditions that share the same letter did not differ significantly ($p > .05$; $N = 8$).

Combined Obstacle and MOUT Course Traversal

A number of analyses were performed on the obstacle/MOUT course data. One analysis was carried out on the combined times to complete both the outdoor obstacle and the indoor MOUT portions of the course. The ANOVA performed on the total time yielded a significant effect of load condition. The means for the load conditions and the results of the post hoc tests are in Figure 19. The post hoc tests revealed that completion times with Rucks B and C were significantly longer than completion time with the No Ruck condition and that times for the rucksacks did not differ significantly.

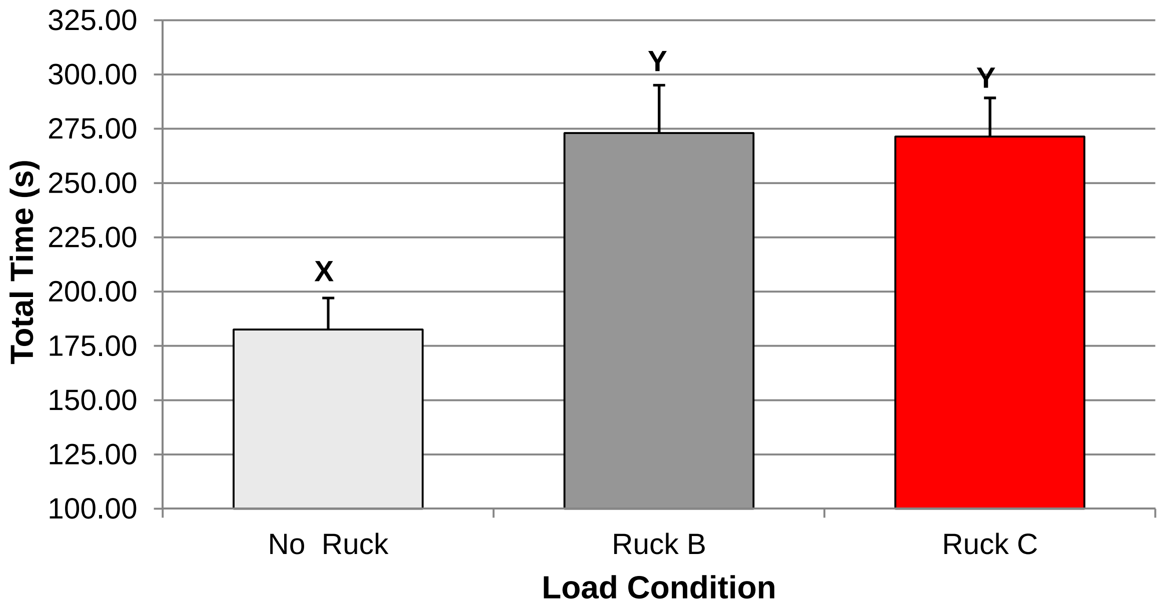

Figure 19. Mean (+1 *SEM*) combined obstacle and MOUT course completion time for each load condition. Load conditions that do not share the same letter differed significantly in post hoc tests ($p < .05$; $N = 7$).

Separate analyses were carried out on the times to complete individual segments of the course. The ANOVAs revealed a significant effect of load condition on all segments. For each segment except the ramp, completion times were significantly longer with Rucks B and C than with the No Ruck condition, and the times for the rucksacks did not differ significantly. On the ramp, the longest completion times occurred with Ruck B. The times for this rucksack were significantly longer than those for the No Ruck condition. Times for Ruck C did not differ significantly from those for either the No Ruck or the Ruck B conditions. The means and the *SEM* for the individual segments are presented in Figure 20, along with the results of post hoc tests.

Range of Body Motion

The volunteers performed simple body movements in each of the three load conditions. The maximum extent of motion in each condition was measured and the ROMs compared to assess the amount of restriction induced by each rucksack. An ANOVA was performed for each

movement except kneel and rise. That movement required the volunteers to assume a kneeling position and then return to a standing position. The ROM was not measured, but the volunteers' success in performing the movement was rated by the investigator. Regardless of load condition, all volunteers executed this movement without assistance.

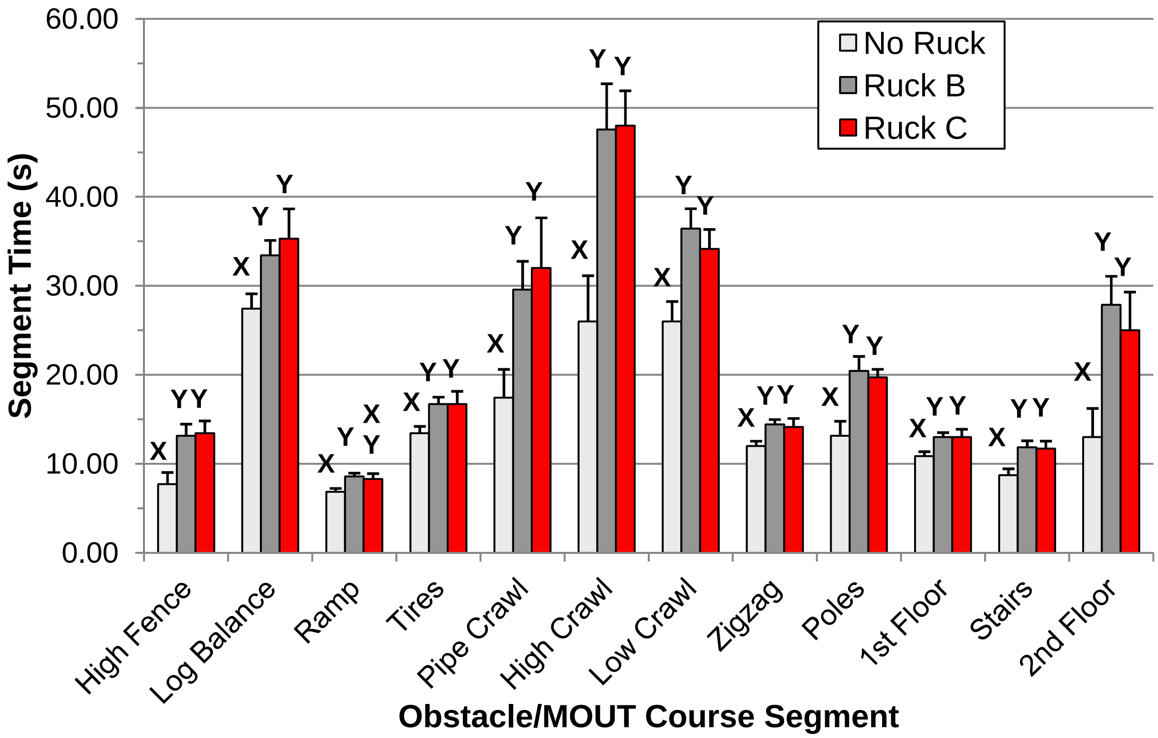

Figure 20. Mean (+1 *SEM*) completion time for individual segments of the combined obstacle and MOUT course for each load condition. Load conditions that do not share the same letter differed significantly in post hoc tests ($p < .05$; $N = 7$).

The mean scores for the movements that were analyzed are presented in Figures 21 through 24. As indicated in the figures, none of these movements yielded a significant effect of load.

Subjective Assessment

The 15-category Borg (1970) RPE rating scale (Appendix A) was administered to the volunteers upon completion of selected study activities to assess the perceived exertion associated with wearing a particular load configuration while performing a particular activity. The RPSD questionnaire (Appendix B; Corlett & Bishop, 1976) was also administered at selected points in the study to obtain ratings of pain, soreness, discomfort, or restriction experienced by the volunteers as they executed testing activities in a particular load condition. In addition, the investigators devised study-specific questionnaires to query volunteers about particular aspects of the load configurations, including compatibility of the load configurations with other personal equipment. Further, the investigators noted, throughout testing, human factors issues associated with use of the load components. The findings for the subjective measures and human factors issues are reported here.

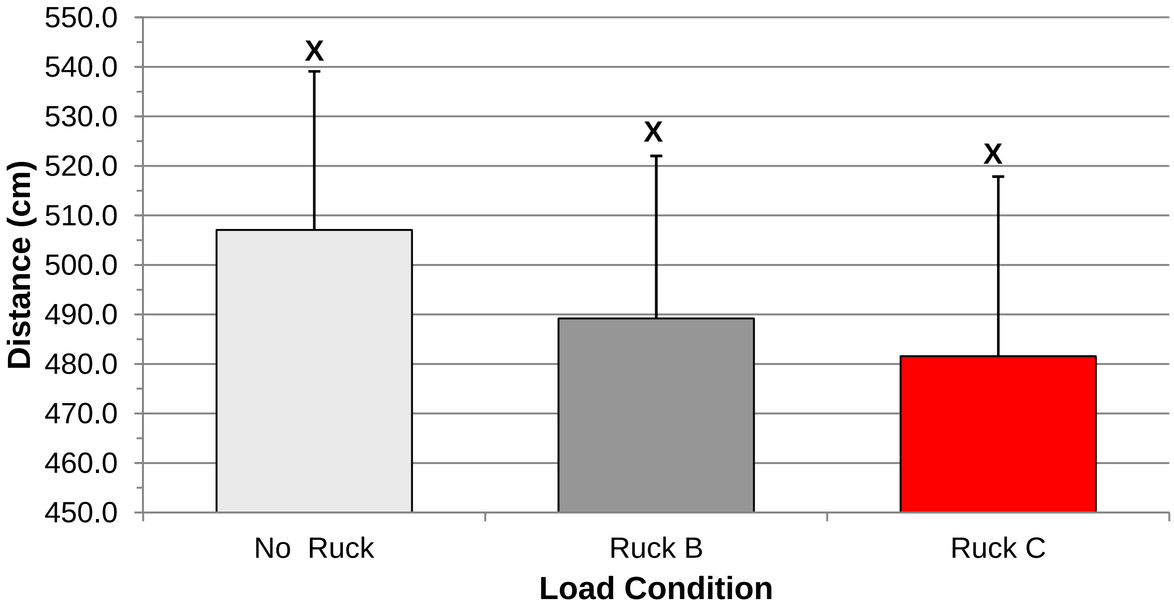

Figure 21. Mean (+1 *SEM*) distance walked in five steps for each load condition. Load conditions that share the same letter did not differ significantly ($p > .05$; $N = 7$).

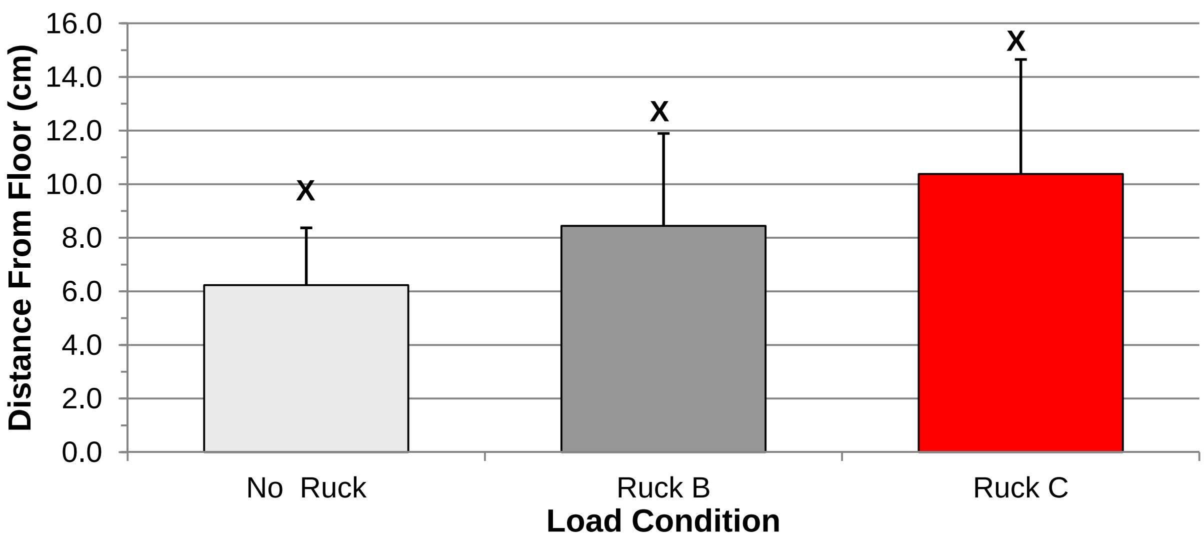

Figure 22. Mean (+1 *SEM*) distance measured from the floor on the standing trunk flexion movement for each load condition. Load conditions that share the same letter did not differ significantly ($p > .05$; $N = 7$).

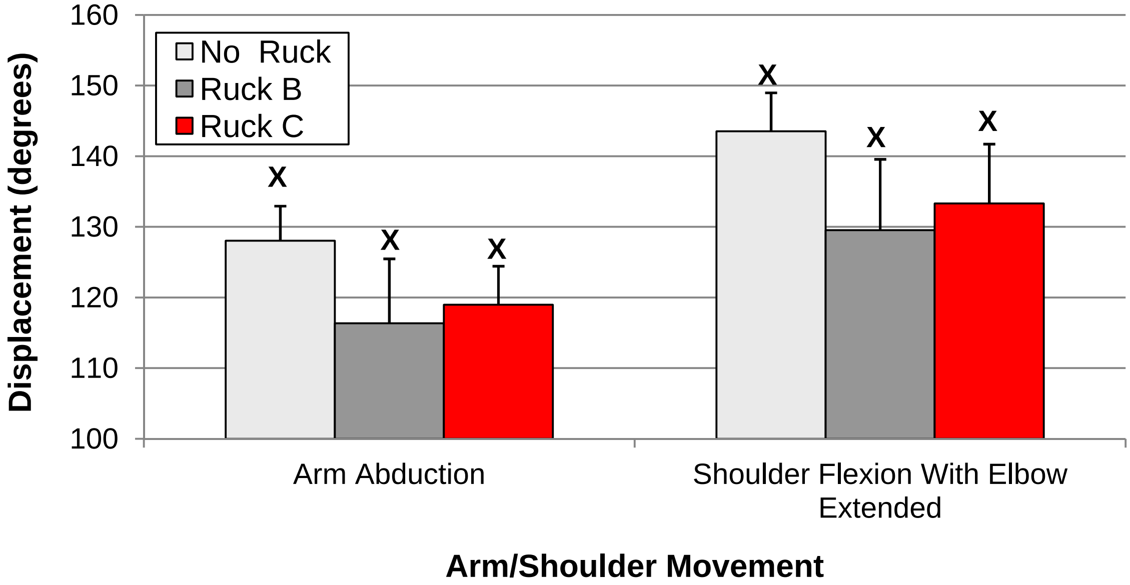

Figure 23. Mean (+1 *SEM*) extent of arm abduction and shoulder flexion with elbow extended for each load condition. Load conditions that share the same letter did not differ significantly ($p > .05$; $N = 7$).

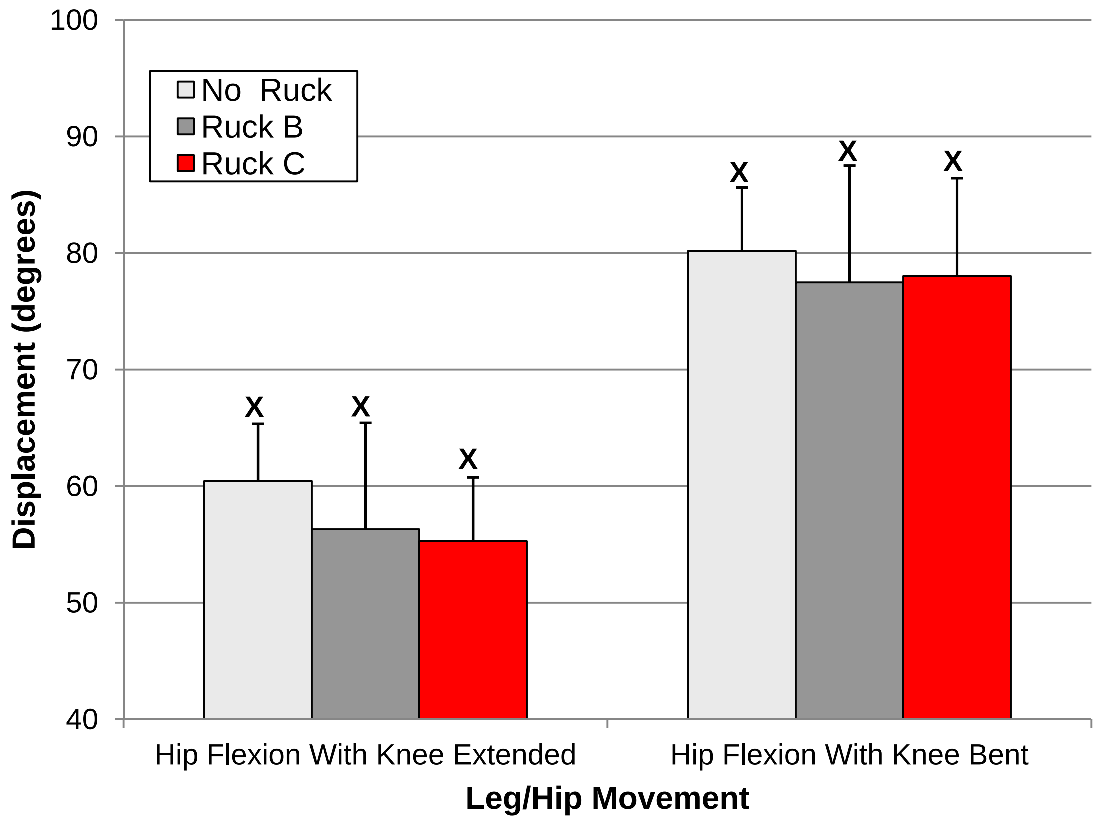

Figure 24. Mean (+1 *SEM*) extent of hip flexion with knee extended and hip flexion with knee bent for each load condition. Load conditions that share the same letter did not differ significantly ($p > .05$; $N = 7$).

Borg RPE

A significant effect of load condition was obtained in the ANOVAs performed on the RPEs given at the end of treadmill walking at 0% and 9% grades and treadmill running at 0% grade. The mean ratings for the activities are presented in Figure 25, along with the results of the post hoc tests. As can be seen, the relationships among load conditions were the same for both walking activities. That is, the ratings for Rucks B and C were significantly higher than those for the No Ruck condition and the ratings for the two rucksacks did not differ significantly. The ratings for running differed from those for walking to the extent that, although the No Ruck condition again yielded the lowest ratings, the ratings for Ruck B did not differ significantly from those for the No Ruck condition. Also, the Ruck B ratings were not significantly different from the highest ratings, which were for Ruck C (Figure 25).

The mean RPE ratings given at the conclusion of the 30-m rush, the box lift and carry, and the obstacle/MOUT course activities are presented in Figure 26. A significant effect of load condition was obtained in the ANOVA performed on each of these activities. For the rush and the obstacle/MOUT course, the exertion ratings given Ruck B and Ruck C did not differ from each other and were significantly higher than those given to the No Ruck condition. On the repetitive lifting task, the highest scores, those for Ruck B, differed significantly from the lowest scores, those for the No Ruck condition; the scores for Ruck C did not differ significantly from those for either of the other two conditions.

Ratings of Pain, Soreness, Discomfort, and Restriction

On the RPSD, the volunteers were to use a 5-point scale, which ranged from 1 (*none*) to 5 (*extreme*), to rate the pain, soreness, discomfort, or restriction that they were experiencing on specific parts of the front and back of the body. The vast majority of ratings given were values of 1 or 2 (*none* or *slight*), and only two volunteers gave any ratings greater than 2 (*slight*). Therefore, the RPSD data were not subjected to statistical analyses. Instead, for each task activity, the number of volunteers giving a rating of at least *slight discomfort* to one or more sites on the front of the body was tallied. A tally was also done for sites on the back of the body. These data are presented in Figure 27.

The periods of walking at 0% and 9% grades tended to elicit ratings of at least *slight discomfort* from more of the volunteers than the other task activities (Figure 27). With regard to walking at 0% grade, the smallest number of volunteers reported discomfort at the front and the back of the body when a rucksack was not worn. The largest number of volunteers gave a rating of at least *slight discomfort* at the front of the body when Ruck B was worn and at the back when Ruck C was carried during walking at a 0% grade. For walking at 9% grade, the fewest volunteers reported discomfort at the front and the back when wearing Ruck C. The specific sites on the front of the body that received ratings of at least *slight discomfort* during walking with either rucksack were similar for both grades. These were the shoulders and the chest. For the back of the body, the upper and the lower back were the sites that received these ratings.

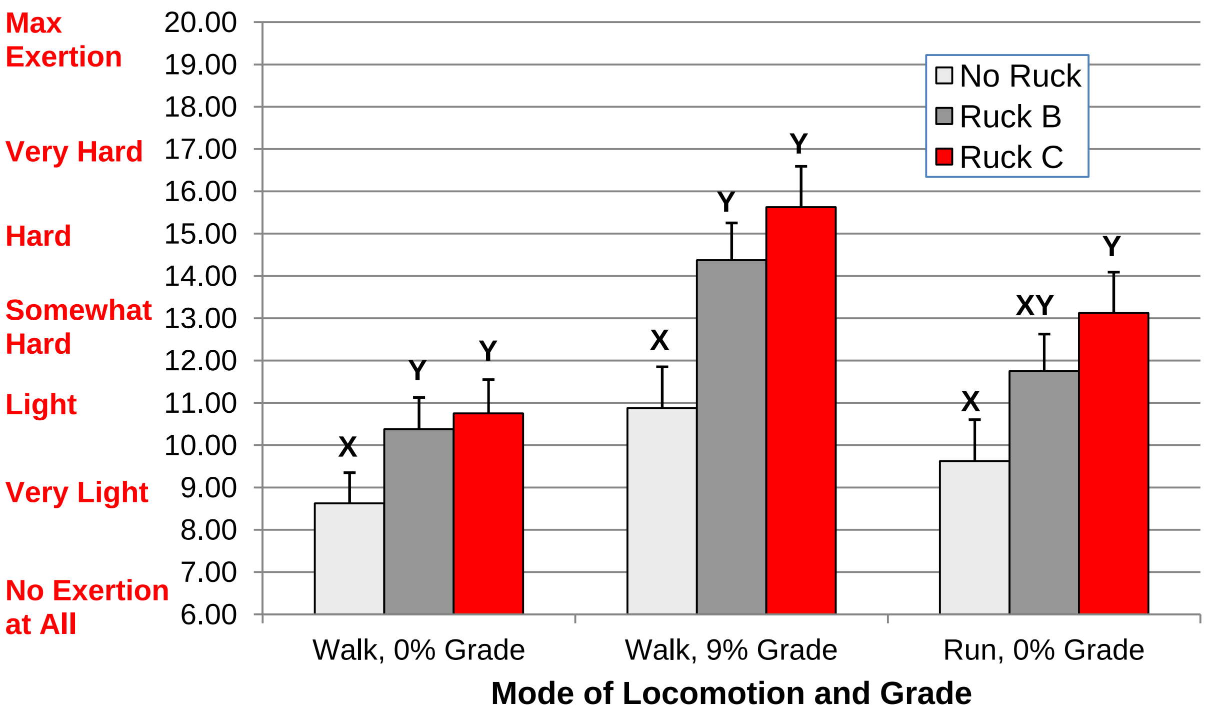

Figure 25. Mean (+1 *SEM*) Borg RPE ratings for each load condition on three locomotor activities. For an activity, load conditions that do not share the same letter differed significantly in post hoc tests ($p < .05$; $N = 8$).

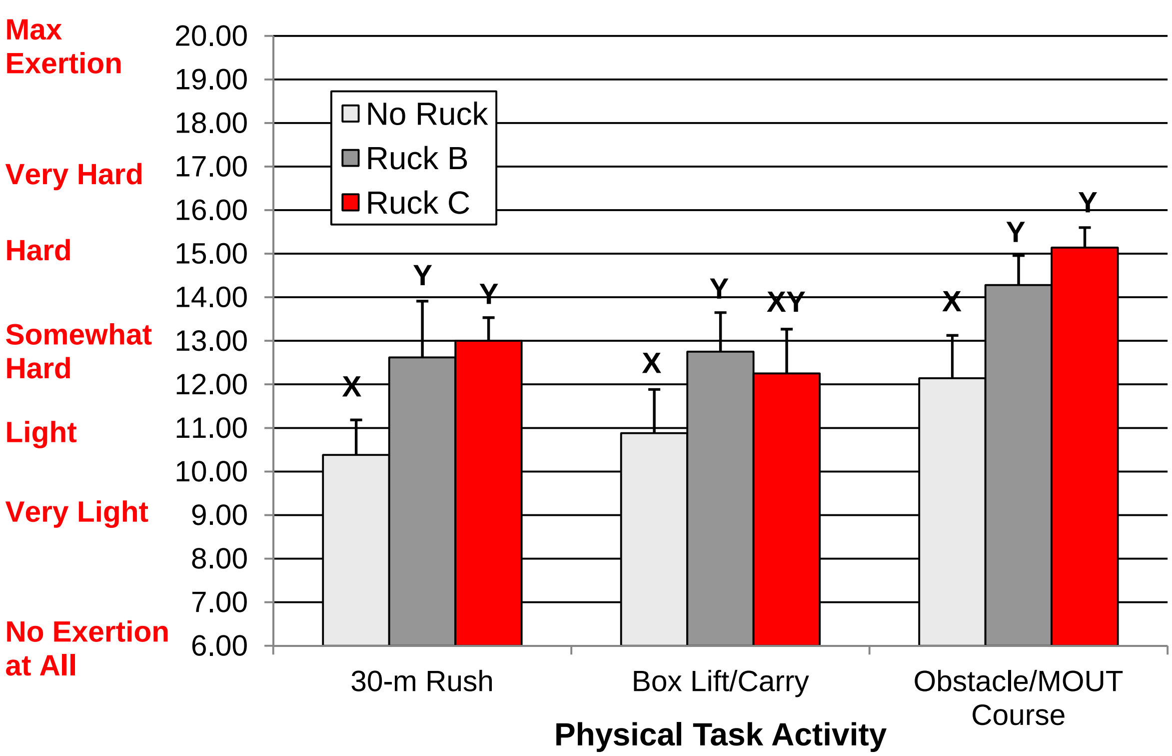

Figure 26. Mean (+1 *SEM*) Borg RPE ratings for each load condition on three physical task activities. For an activity, load conditions that do not share the same letter differed significantly in post hoc tests ($p < .05$; $N = 8$).

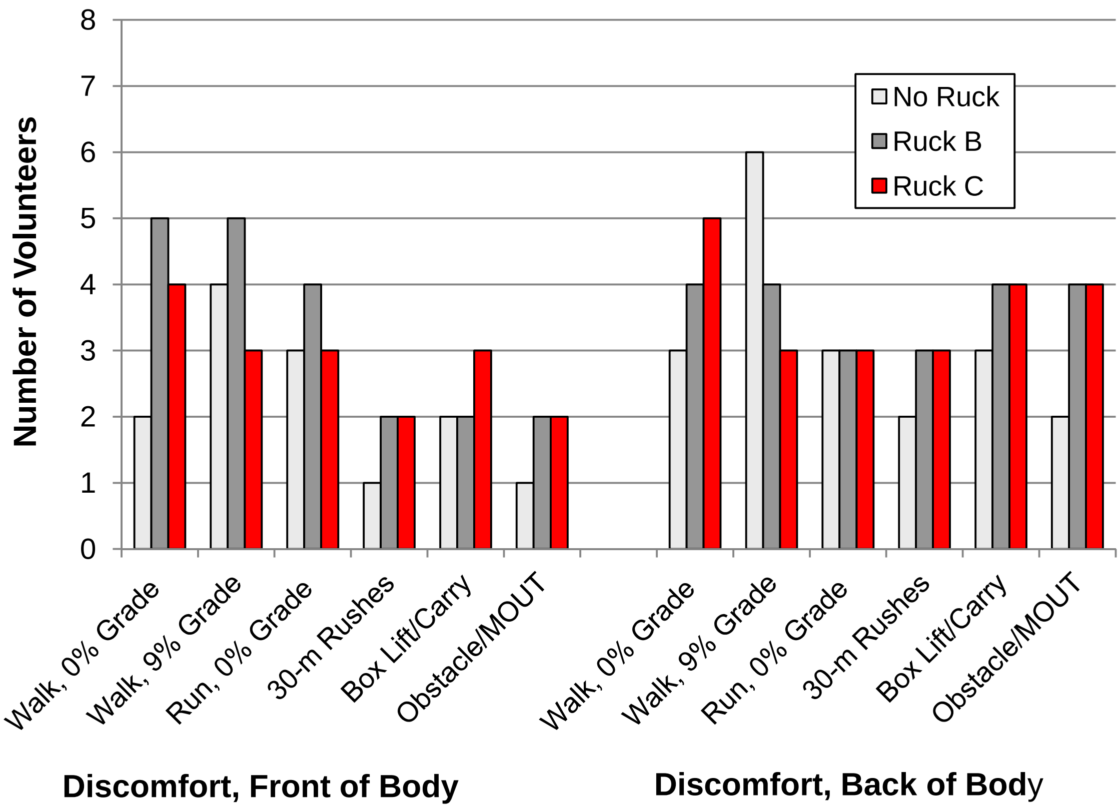

Figure 27. Number of volunteers giving a rating of at least slight pain, soreness, discomfort, or restriction for each load configuration and task activity (N = 8).

For the period of running and the three physical activity tasks (30-m rush, repetitive box lift and carry, and combined obstacle/MOUT course), the lowest number of responses of at least *slight discomfort* was generally associated with the condition in which a rucksack was not worn (No Ruck), and the number of volunteers giving a rating of at least *slight discomfort* was about the same for the two rucksacks (Figure 27). The specific sites on the body receiving ratings of at least *slight discomfort* were similar for running and the three physical activities. At the front of the body, the sites were the shoulders, the chest, and the hips. At the back of the body, the upper and the lower back and the back of the lower legs received ratings of at least *slight discomfort* when either rucksack was carried.

Human Factors Issues and Responses on Study-Specific Questionnaires

During a portion of the study, the volunteers executed a number of movements with and without the rucksacks. The investigators observed the ease with which the movements could be carried out and sought feedback from the volunteers regarding any problems encountered. Personal equipment items were also used with the rucksacks and the compatibility among the items was assessed. Questionnaires devised by the investigators were used to obtain the volunteers' opinions regarding ease of movement and features of the rucksack designs. Investigators' observations and volunteers' reports germane to human factors issues, design of the rucksacks, and rucksack preferences are presented here.

Rucksack Donning and Doffing and Compatibility With Personal Equipment

During their time in military training, prior to participating in the study, the volunteers had used the ACH, the SAPI plates, and the predecessor to the IOTV, which is designated as the Outer Tactical Vest; the volunteers had not used the IOTV or the TAP. With some familiarization, the volunteers were able to don and adjust the IOTV and the TAP without assistance. They were also able to don and adjust Rucks B and C without assistance. Learning to adjust the shoulder straps of Ruck B did, however, require familiarization. The volunteers initially pulled directly downward on the shoulder strap webbing to tighten the straps, although tightening required that the webbing be pulled toward the back of the body. Volunteers became accustomed to tightening the shoulder straps in this manner. Some volunteers found that tightening the shoulder straps was accomplished most easily by bending forward at the waist and then pulling the webbing toward the back. All volunteers were able to doff the rucksacks quickly and without assistance.

The volunteers' responses to questions on donning, adjusting, and doffing the rucksacks and compatibility of the rucksacks with the other equipment they were wearing (i.e., the IOTV with front and back plates, the TAP, and the ACH) are presented in Figure 28. The data indicate the number of volunteers who agreed with statements regarding various aspects of use of the rucksacks. All volunteers indicated that the rucksacks were compatible with wear of the IOTV, the TAP, and the ACH. The greatest difference between the rucksacks was in ease of adjustment. Seven of the eight volunteers responded that Ruck C was easy to adjust, whereas five of the eight were of the opinion that adjustment of Ruck B was easy. It was also observed that the hip belts of both Ruck B and Ruck C were not positioned below the bottom edge of the IOTV on some volunteers. Rather, the hip belt passed around a portion of the torso covered by the IOTV. With this relationship, it is unlikely that the belt transferred the rucksack load to the hips as it was designed to do. However, none of the volunteers indicated that the location of the hip belt was a problem.

Weapon Aiming

The volunteers assumed prone, kneeling, and standing (unsupported) firing positions and attempted to aim the simulated M4 carbine at a target outline mounted directly in front of them. This was done with the volunteers outfitted in each load condition. All volunteers were able to assume the body positions, regardless of whether a rucksack was worn. However, shouldering of the weapon was problematic in all firing positions when either of the rucksacks was used. With the rucksack shoulder straps lying over the shoulder portion of the IOTV, the butt of the weapon could not be "pocketed" against the shoulder. Volunteers, instead, placed the butt of the weapon against the upper arm. There were also occasions, in the prone firing position, when the brim at the back of a volunteer's helmet contacted the top of the rucksack as the head was raised to aim the weapon. This occurred with both Ruck B and Ruck C. The interference made it difficult to raise the head to sight the weapon and pushed the helmet lower on the forehead, down toward the eyes.

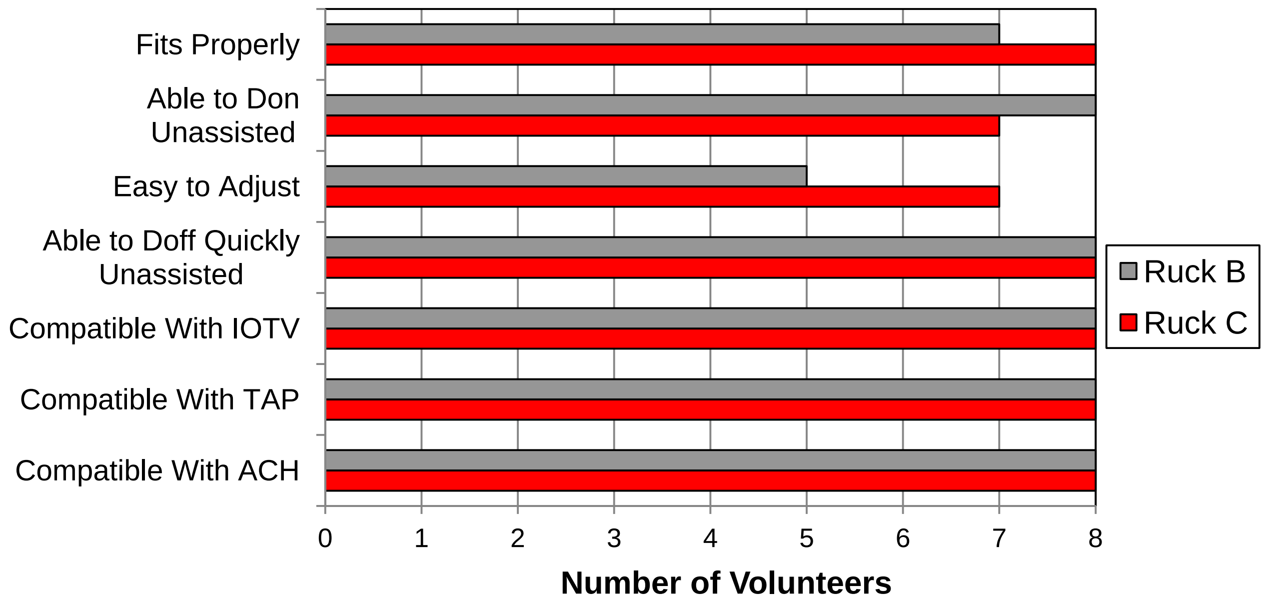

Figure 28. Number of volunteers agreeing with each statement pertaining to donning and doffing and compatibility of rucksacks with other personal equipment (N = 8).

The volunteers rated, on a 7-point scale (from *very easy* to *very difficult*), the ease or difficulty in assuming each of the three firing positions. The median ratings are presented in Figure 29. It can be seen that the median ratings without a rucksack were more positive than those for either rucksack condition. However, no significant differences were obtained on the Friedman two-way analysis of variance by ranks (Marascuilo & McSweeney, 1985; Siegel & Castellan, 1988), which was applied to the data for each firing position to contrast the ratings given to the load conditions.

Opinions of Task Difficulty and Compatibility of Load Conditions With Military Environments

One item posed to the volunteers on the study-specific questionnaire asked them to rate, on a 7-point scale (from *much easier* to *much more difficult*), how much easier or more difficult it was to perform a number of task activities with a rucksack than without one. The median ratings are presented in Figure 30. The medians indicate that the volunteers considered it to be *slightly* to *somewhat more difficult* to perform task activities when wearing either of the rucksacks compared with wearing an IOTV, a TAP, and an ACH without the addition of a rucksack. The greatest differences between Rucks B and C in their respective median ratings were for running on a level surface and doing the 30-m rushes. For both these activities, Ruck C received the more-negative ratings. The sign test (Marascuilo & McSweeney, 1985; Siegel & Castellan, 1988) was employed to contrast the ratings given to Rucks B and C on these and the other task activities. No significant differences were obtained.

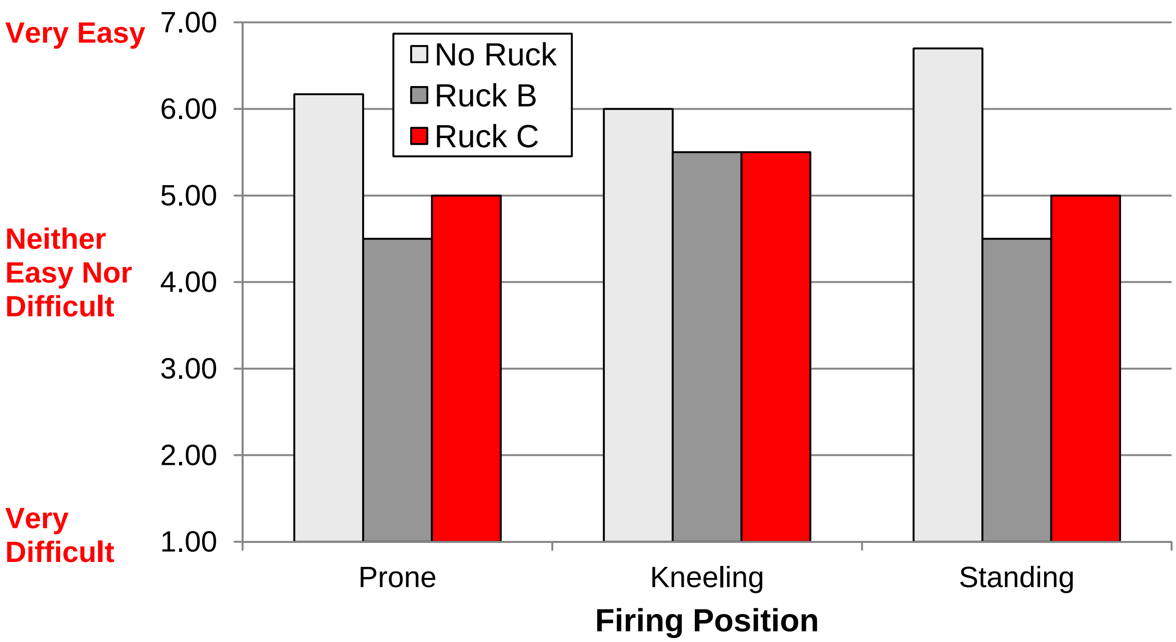

Figure 29. Average (median) ratings of ease/difficulty of assuming weapon firing positions for each load condition (*N* = 8).

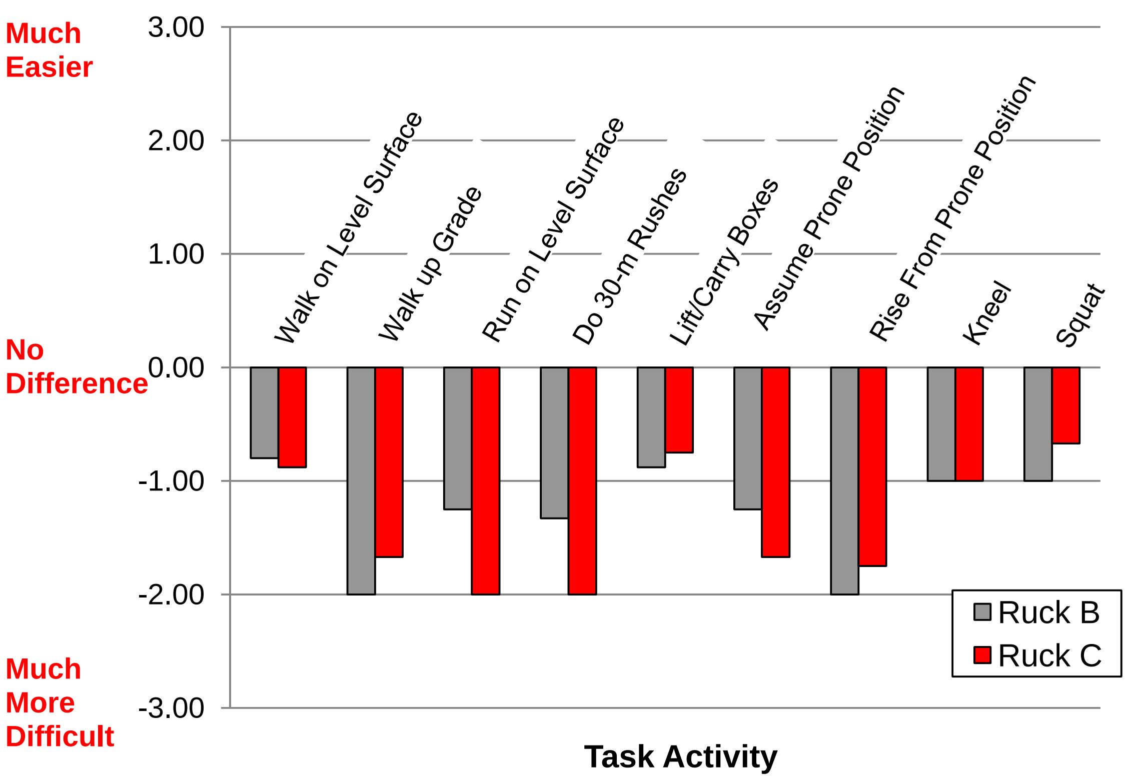

Figure 30. Average (median) ratings of ease/difficulty of performing task activities with Ruck B and Ruck C compared with the No Ruck condition (*N* = 7).

On another question, the volunteers were asked to consider, based upon their military field experience, whether the components of the three load conditions would be compatible for use in various military environments. The likelihood that the configurations could be used successfully was rated on a 5-point scale (from *very likely* to *very unlikely*). The median ratings are in Figure 31. Ruck C was the only load condition for which the median ratings indicated that it was unlikely to be used successfully. The *unlikely* ratings were associated with two environments, in a high mobility multipurpose wheeled vehicle (HMMWV) and in wooded terrain (Figure 31). A Friedman two-way analysis of variance by ranks (Marascuilo & McSweeney, 1985; Siegel & Castellan, 1988) performed on the data for each environment revealed a significant difference among load conditions for the HMMWV and the wooded terrain environments. The significant findings were attributable to the negative ratings given to Ruck C, compared with the other conditions.

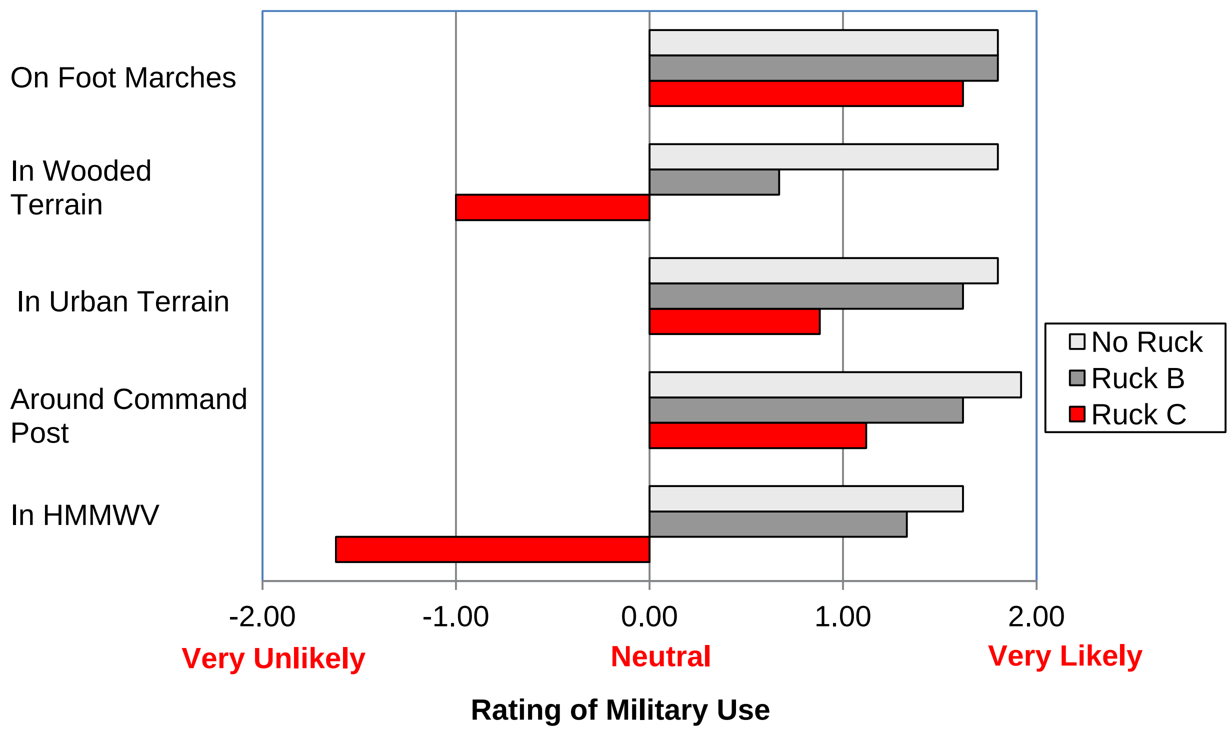

Figure 31. Average (median) ratings of using each load condition successfully in various military environments (N = 7).

Opinions of Rucksack Design Features and Preferred Rucksack

To assess their opinions of the design characteristics of the rucksacks, questions were posed to the volunteers in the form of statements about elements of the rucksacks and their functioning. Volunteers were to indicate whether they agreed or disagreed with the statements. Seven of the eight volunteers were available to respond to this question. In Figure 32, the number of volunteers who agreed with each statement is presented for each rucksack. The data indicate that the rucksacks did not differ by more than one in terms of the number of volunteers agreeing with each statement. Where there were these small differences between rucksacks, Ruck B had the higher number of volunteers agreeing with the statement.

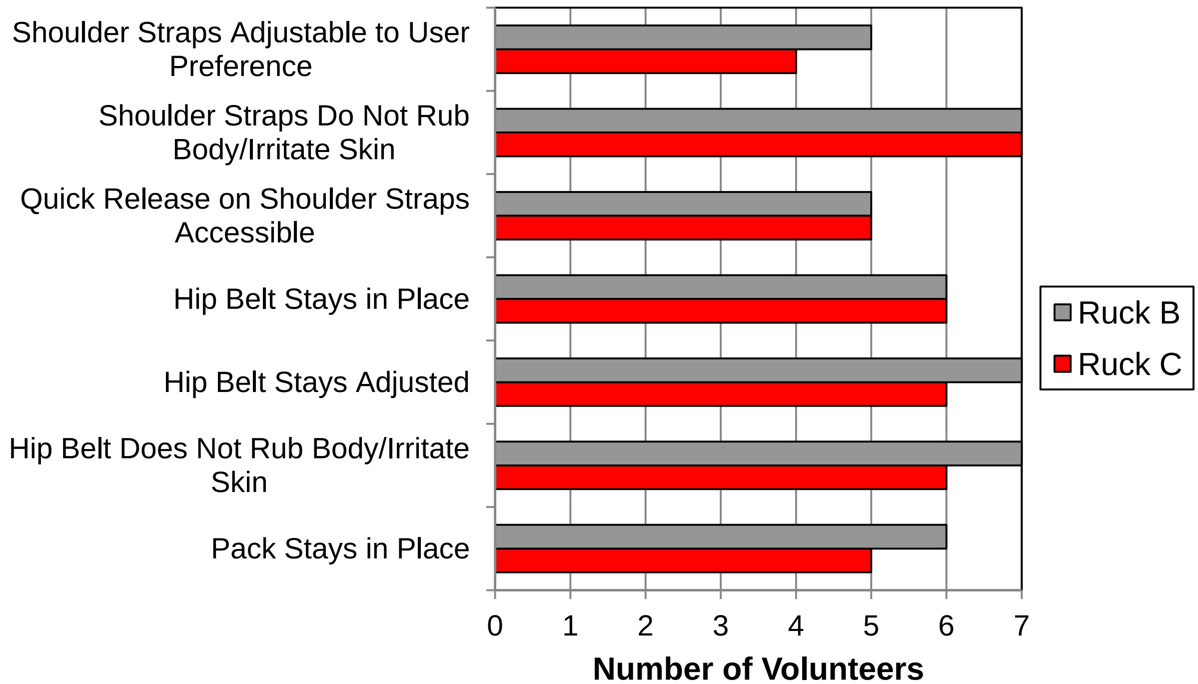

Figure 32. Number of volunteers agreeing with each statement pertaining to design features or functioning of the rucksacks (N = 7).

A question posed to the volunteers at the completion of their testing entailed listing, for both Rucks B and C, the features that they liked best and those that they liked least. A summary of the volunteers' responses is presented in Table 11. Volunteers were then asked to select the rucksack they would prefer to use in the future as an Army rucksack and to explain the reasons for their selection. Again, seven of the eight volunteers were available to respond to these questions. Ruck B was selected as the preferred rucksack by six of the seven respondents; the seventh volunteer selected Ruck C. The reasons given by the volunteers for their selections were compiled and are presented in Table 12.

Table 11. *Summary of Volunteers' Listings of Most Liked and Least Liked Features of the Rucksacks (N = 7)*

Most Liked Features	Least Liked Features
Ruck B	
• Pack bag fits well against back • Good distribution of load weight on body • Ruck stable on body during movement • Ruck stays in place during movement; pack bag does not bounce up and down against back • Straps easy to adjust • Quick release works well	• Feel load weight on lower back at times • Too many straps • Straps too long; they get in the way • Ruck difficult to don and adjust without assistance • Shoulder straps difficult to adjust
Ruck C	
• Ruck well balanced on body • Shoulder straps well cushioned; ruck comfortable at shoulders • Buckle on hip belt easy to open and close	• Feel load weight on lower back at times • Foam cylinders on pack bag uncomfortable against back • Load weight uncomfortable to bear at hips • Ruck difficult to adjust

Table 12. *Reasons Given by Volunteers for Their Selection of Preferred Rucksack (N = 7)*

Preferred Rucksack: Ruck B
(Selected by 6 of 7 Volunteers)

- Feel most of load weight on shoulders, not on lower back; minimal strain on lower back with this ruck
- Hip belt holds pack bag during movement; pack bag does not move side to side
- Ruck very stable on body; pack bag does not bounce up and down on back
- Straps easy to adjust
- Load weight evenly distributed on body
- Easy to maneuver while wearing this ruck
- During low crawl, ruck does not ride up and push down on back of head

Preferred Rucksack: Ruck C
(Selected by 1 of 7 Volunteers)

- Ruck comfortable to carry when adjusted properly
- Ruck stable on body
- Feel load weight on shoulders, not on upper and lower back

DISCUSSION

Implications of Load Mass

Throughout testing, the Soldier-volunteers wore clothing and individual equipment items that comprise a fighting load for dismounted troops. The load consisted of an ACU, combat boots, an IOTV with front and back ESAPI plates, a TAP, an ACH, and a simulated M4 carbine. At 17 kg, the mass of the fighting load was approximately 23% of the mean nude body mass of the volunteers. The addition of either 23-kg rucksack to the fighting load raised the external load on the body to 53% of the volunteers' mean nude body mass. As hypothesized based upon the physiological literature (Pandolf et al., 1977; Polcyn et al., 2002; Sagiv et al., 1994; Soule et al., 1978), energy usage expressed as $\dot{V}O_2$ scaled to body mass was significantly higher when either rucksack was worn than when the fighting load alone was used during treadmill walking at 1.34 $m \cdot s^{-1}$ on 0% and 9% grades.

Compared with the walking data at 0% grade without a rucksack, mean $\dot{V}O_2$ scaled to body mass was higher by approximately 14% when Ruck B or Ruck C was used at this grade. At the 9% grade, mean energy costs scaled to body mass for Rucks B and C were higher by about 13% than the energy cost without a rucksack. Statistical analyses were not carried out to compare energy costs for walking at the 0% and the 9% grades, but inspection of mean $\dot{V}O_2$ values scaled to body mass indicated that, regardless of load condition, the values at the 9% grade were approximately 63% higher than those at the 0% grade, a result in line with the literature (Hasselquist et al., 2009). The findings from the current study illustrate the energy demand that marching with loads places on Soldiers, particularly when operations are conducted in mountainous terrains. The energy used carrying loads is of critical concern in military operations because the greater the amount of energy consumed during a foot march, the less likely it is that Soldiers will have the physical stamina to deal successfully with the post-march challenges of a mission, such as encountering the enemy (U.S. Department of the Army, 1990).

The mean RPEs that the volunteers assigned upon completion of each 10-min bout of walking were in consonance with the energy consumption data. The RPEs were higher for conditions in which either rucksack was carried than when the fighting load alone was used. Further, the overall RPEs assigned to walking at 9% grade were higher than those assigned to walking or to running at 0% grade.

For each load condition, the RPE for running was somewhat higher than the RPE for walking at 0% grade and lower than the RPE for walking at 9% grade. It is possible that the RPEs for running would have been higher if a faster speed had been imposed. In pilot testing, a running speed of 2.46 $m \cdot s^{-1}$ was used. However, individuals struggled to maintain that speed for 10 min when carrying a rucksack. Therefore, a lower speed, 2.24 $m \cdot s^{-1}$, was used for the study, and metabolic data were not collected during running in order to avoid the possibility that the volunteers would experience respiratory discomfort while wearing the mask of the $K4b^2$ metabolic analysis apparatus. Volunteers were able to complete the run at this speed successfully under each load condition. When running at 2.24 $m \cdot s^{-1}$ without a rucksack, the volunteers exhibited a flight phase typical of a running gait, but a flight phase was rarely achieved when either rucksack was carried. Rather, the gait pattern tended to be a "shuffling" of the feet.

Like the energy consumption measure, measures of GRF revealed the negative effects of adding a 23-kg rucksack load. When the volunteers walked with a fighting load alone, average vertical GRFs at foot contact were substantial, achieving 1.4 to 1.5 times body weight. During running with the fighting load, average vertical GRF at foot contact was higher, at about 2.2 times body weight. As hypothesized, the effect of adding a 23-kg rucksack load was to increase the forces to which the body was exposed during locomotion significantly beyond those experienced with no rucksack. When normalized to the body mass of study participants, peak vertical GRFs at foot contact and at push off during walking at the 0% grade with either rucksack were about 20% higher than the respective forces without a rucksack. Comparable data for walking at the 9% grade revealed peak vertical GRFs at foot contact and at push off with either rucksack to be higher in magnitude by about 30% and 15%, respectively, than peak vertical GRFs without a rucksack. During running, peak vertical force at foot contact with either rucksack exceeded that force without a rucksack by about 14%. As was also hypothesized, peak braking and peak propulsive forces adjusted for body mass were significantly higher for walking at both the 0% and the 9% grades when either rucksack was carried compared to forces without a rucksack. In the case of running, both peak braking and propulsive forces were higher with the rucksacks, although the difference obtained in post hoc tests of peak braking force did not achieve statistical significance after adjusting for multiple comparisons.

These findings are in consonance with other studies in which gait kinetics were examined for effects of varying the masses of external loads borne on the body (Harman et al., 1999a, 1999b; Hasselquist et al., 2009; Polcyn et al., 2002). Repeated exposures of the body to the high magnitude forces that occur every time the foot contacts and subsequently pushes off from the ground have been postulated to contribute to the onset of acute and chronic injuries, particularly overuse injuries of the lower extremities (Knapik et al., 1996). A consequence of increasing already high GRFs by increasing the mass of the external load on the body is to increase the probability of incurring such injuries.

Like the kinetic data, the kinematic data reflected the effects of the presence and the absence of the 23-kg rucksack loads. For walking and running at 0% grade, the proportion of the gait cycle spent in the stance phase was significantly larger when either rucksack was worn than when no rucksack was worn, and, accordingly, the proportion of the cycle spent in the swing phase was significantly smaller. These findings were as hypothesized and reflect results presented in the literature on load mass effects during walking and running at experimenter-controlled speeds (Harman et al., 2000; Kinoshita, 1985; Martin & Nelson, 1986). For walking at 9% grade, the data for stance duration and swing duration as a percentage of stride time were in the hypothesized direction, but the differences in these variables with and without a rucksack did not achieve statistical significance in post hoc tests after adjusting for multiple comparisons.

Increased stance durations and decreased swing durations with loads are likely the result of increased demands on the muscles to support the greater weight during stance and to redirect and accelerate the greater mass during step-to-step transitions (Griffin, Roberts, & Kram, 2003). The proportion of the gait cycle spent in double support was larger with a rucksack than without one during walking at 0% and 9% grades. Longer double support times should result in improved body stability (Harman et al., 2000). The double support period is the portion of the gait cycle

when the body has the largest base of support and is thus most stable. It is possible, as well, that increasing the time spent with both feet in contact with the ground decreases the internal load on the joints in the lower extremities.

The maximal performance tests included in the current study also provided evidence of the negative effects of bearing the 23-kg rucksack load. The combined obstacle and MOUT course traversal times and the total time to complete the five 30-m rushes were, as hypothesized, significantly longer with than without a rucksack. Use of either rucksack extended average completion times for the course traversals and the 30-m rushes by about 48% and 30%, respectively. Analyses of times to complete each of the five run portions of the 30-m rushes and the four transition portions of the rushes indicated that, both with and without a rucksack, there was an apparent fatigue effect, reflected in slower times after the initial rushes and transitions. However, individual rush times and transition times were consistently faster without a rucksack. Results on the third maximal performance test, the box lift and carry task, were in the hypothesized direction insofar as there were fewer repetitions with than without a rucksack. However, the differences among test conditions did not achieve significance in post hoc tests after adjusting for multiple comparisons.

The poorer maximal performance, higher energy consumption, and higher magnitude GRF found with the 23-kg rucksack load compared with the 17-kg fighting load alone are evidence of the negative impacts that bearing external loads on the body are likely to have on Soldiers as they conduct foot marches and engage in military field operations. To assess whether factors other than load mass may have contributed to differences obtained between the fighting load only and the fighting load plus rucksack conditions, ROM about body joints was measured. It was found that wear of the rucksacks did not restrict movements significantly compared with use of the fighting load alone. Also, additional analyses were carried out on the energy consumption and the GRF data to further explore the contribution of other factors. For these analyses, $\dot{V}O_2$ and GRF values were adjusted to a volunteer's total mass (i.e., body mass plus the mass of all items worn or carried on the body).

When scaled to total mass, $\dot{V}O_2$ and two GRF variables yielded significant differences among load conditions. The GRF variables affected were peak vertical thrust at push off when walking at 9% grade and peak braking force when running at 0% grade. For both variables, peak force was significantly greater with the fighting load alone than with either of the rucksacks, and the values for the rucksacks did not differ significantly. Peak vertical impact force at foot contact for running showed a trend toward higher magnitude forces without than with a rucksack, but the difference was not significant in post hoc tests. The analysis of $\dot{V}O_2$ scaled to total mass for walking at the 9% grade revealed that energy cost was significantly higher, by about 9%, when the fighting load alone was used than when either rucksack was also carried. For the 0% grade, the values with the fighting load alone were again higher, by about 8%, than those with either rucksack, although the differences were not significant in post hoc tests.

The 17-kg fighting load included simulated, appropriately weighted ammunition and grenades located in pouches on the front of the upper torso and there was no equivalent weight on the back. Trunk lean angle was not measured in the current study. However, Gregorczyk et al. (2010) and LaFiandra et al. (2003) reported that Soldiers walking with a fighting load, but

without a load on the back, maintained an upright posture relative to the vertical, and there was even evidence of a slight backward inclination of the upper trunk. In contrast, forward lean of the trunk is typical when a rucksack is carried and the lean angle tends to increase as the load mass on the back is increased (Harman et al., 2000; Kinoshita, 1985; Polcyn et al., 2002).

In a study in which both trunk lean and energy cost adjusted to total mass were analyzed, Gregorczyk et al. (2010) obtained results similar to those obtained in the current research. Gregorczyk et al. tested male Soldiers walking at a speed of 1.34 $m \cdot s^{-1}$ at 0% grade carrying a 20-kg fighting load alone and carrying an additional 20-kg rucksack load. Compared with the fighting load plus the rucksack, energy cost adjusted to total mass was about 8% higher and forward trunk lean 11 degrees less with the fighting load alone. In the current study and in the research by Gregorczyk et al. (2010), distribution of the load may have affected $\dot{V}O_2$ scaled to total mass. It can be postulated that the COM of the body-plus-load system was low and toward the front of the body with the fighting load only, whereas it was higher and toward the back of the body when the rucksack load was added. If this were the case, raising the COM and redirecting it to propel the body-plus-load system forward into the next step may have required more energy per unit total mass when the fighting load alone was worn than when the rucksack load was also carried. The finding in the current study that, after adjustment to total mass, peak vertical thrust force for walking at 9% grade was significantly higher with the fighting load alone and peak vertical impact force for running was higher with only the fighting load as well, although not significantly so, may be a further indication of the effects of distribution of the load on the body.

Comparison of Rucksack Prototypes

The quantitative metrics associated with the physiological, biomechanical, and maximal performance data for the rucksack prototypes did not reveal statistically significant differences between Rucks B and C. Unlike the research into load mass effects, the extant literature pertaining to the effects on these metrics of rucksacks of the same mass, but different in design, did not provide a basis for hypothesizing on the likely outcomes when contrasting Ruck B and Ruck C.

The COMs of the two rucksack prototypes were measured as part of the current study and were found to be highly similar. The COM values along an axis differed by 2 cm or less. In their study of the effects of load location in a backpack, Obusek et al (1997) found significant differences in energy consumption, but the COMs of the loads in that study differed substantially. The values differed by 27 cm along the longitudinal axis and by 11 cm along the anterior-posterior axis. From the findings of the current study and those of Obusek et al. (1997), it can be postulated that the COMs of the two rucksack prototypes were too similar to result in statistically significant differences in energy consumption. It seems reasonable to expect that energy consumption effects would be obtained with load COM differences between the extremes of those of the current study and those examined by Obusek et al. (1997). However, research has not been done to explore this.

There is only limited research, as well, comparing the effects of rucksacks loaded to the same mass on biomechanical measures captured during locomotion. Harman et al. (1999a,

1999b) conducted two such studies, testing two rucksacks that differed in design and in location of COM in each study. They reported that the COM of one pack was higher than that of the other by 7 to 8 cm along the longitudinal axis in one study and by 5 to 6 cm in the other. The participants walked at 1.34 $m \cdot s^{-1}$ on a level treadmill with the loaded rucksacks in both studies. Harman et al. (1999a, 1999b) obtained significant differences in vertical GRFs at foot contact and at push off between the two rucksacks they tested in each study. Although the higher GRF values were associated with the rucksack having the higher COM, there were design differences between the two rucksacks that may also have contributed to the GRF findings.

The rucksack prototypes used in the current study were more similar in design than those used by Harman et al. (1999a, 1999b) and had more similar COMs, factors that are likely to result in a finding of no difference between the rucksacks on the biomechanical measures. Analyses of the data from the current study supported this postulation. The kinematic variables for walking at 1.34 $m \cdot s^{-1}$ on 0% and 9% grades did not yield any differences between the rucksacks. Further, differences were not obtained in analyses of kinematic data for running on the level at 2.24 $m \cdot s^{-1}$.

Analyses of the kinetic data were conducted on the vertical and the anterior-posterior components of GRF scaled to body mass and scaled to total mass. The GRFs scaled to body mass were not differentially affected by the rucksack worn. Also, the data adjusted for total mass did not reveal differences between the rucksacks, indicating that GRFs were not influenced by design differences between the rucksacks. In addition, no significant differences were found between Rucks B and C on measurement of ROM about body joints or on the three tests of maximal performance. The finding that Rucks B and C did not differentially affect the maximal performance tests supported results of relevant past research involving similar tests (Harman et al., 1999a, 1999b; Hasselquist et al., 2009; Kirk et al, 2005; LaFiandra et al., 2003).

Among the references to studies that used maximal performance tests similar to those used here, Harman et al. (1999a, 1999b) and LaFiandra et al. (2003) described the locations of the COMs of their loads, whereas the other reference did not. The COMs are important quantitative descriptors, but how the mass of the load is distributed about a particular axis of rotation is also important when rotary motion of the body is involved, as it was on the combined obstacle and MOUT course and in the 30-m rushes performed in the current study (Martin et al., 1982). Therefore, in addition to COM, MOI of the rucksack prototypes was measured in the current study.

As the mass and the MOI of a rucksack load increase about a given axis, the ability of the load carrier to initiate a change in angular motion about that axis becomes more difficult. Similarly, ceasing that movement once started is more difficult (Hinrichs et al., 1982). Comparisons of the MOIs for the rucksack prototypes indicated that Ruck C had larger values about each principal axis than Ruck B, with the differences between the rucksacks being greater for the MOIs about the x and the z axes than about the y axis. These data suggest that Ruck B may have been easier for the study volunteers to control as they executed the combined obstacle and MOUT course and the 30-m rushes.

Some portions of the combined obstacle and MOUT course involved quick changes in direction about the volunteers' z axis (longitudinal axis). Other portions of the course and the 30-m rushes required rapid movement from a standing to a prone position and a rapid return to a standing position (i.e., quick changes about the y axis [medial-lateral axis]). Having small MOI values about the y and the z axes would, therefore, be more critical than having small values about the x axis (anterior-posterior axis). In the case of both rucksack prototypes, the MOIs about the y and the z axes were smaller than the MOI about the x axis. However, Ruck C had a well-defined intermediate MOI about the z axis, and Ruck B did not. It is undesirable for the MOI about either the y or the z axis to be the intermediate MOI, where its magnitude lies between those of the other two principal MOIs. Rotation about an axis that has an intermediate MOI value is unstable (Greenwood, 1965). Thus, there was the potential for the motion of Ruck C to rotate off the z axis and spin about the x and y axes as well, requiring the Soldier-volunteers to exert muscular force to control the rotation about the intermediate axis.

There were no indications in the results that the respective MOI characteristics of Rucks B and C differentially affected total times to complete the five 30-m rushes or the combined obstacle and MOUT course. The time differences between the rucksacks on these tests were minimal and did not approach the level of statistical significance. Differences between Rucks B and C in mean times for the individual transitions, the portion of the 30-m rush activity most likely to reflect MOI effects, were again minimal, as were means for times to complete individual obstacles or segments of the obstacle and MOUT course. There are a number of possible reasons that differences between the rucksacks in MOI did not have obvious effects on performance. The differences may not have been of sufficient magnitude, the Soldier-volunteers may have made small postural adjustments that were not obvious in their performance, and the physical activities that the volunteers executed may not have been extreme enough to reveal the differences.

Unlike the quantitative physiological, biomechanical, and maximal performance data, the responses of the Soldier-volunteers to the question of which rucksack they would prefer to use in the future clearly distinguished between the two rucksack prototypes: six of the seven volunteers who answered the question selected Ruck B, and only one volunteer selected Ruck C. This finding is in consonance with the preferences expressed by the Soldiers who participated in the field testing of the three, original rucksack prototypes (Richardson, 2010). In that evaluation also, the majority of Soldiers (72%) selected Ruck B, and only a few (3%) selected Ruck C as the rucksack they preferred. The RPE, the RPSD, and the study-specific questionnaires administered in the current study did not yield data predictive of this overwhelming preference of the volunteers for Ruck B.

The RPE and the RPSD were administered at specific points during the current study to assess the volunteers' reactions to the load conditions. Few ratings on the RPSD equated with greater than a slight level of pain, soreness, discomfort, or restriction, and the ratings did not differentiate between the two rucksacks. Similarly, analyses carried out on the RPE responses did not yield statistically significant differences between the rucksacks. The mean ratings of exertion given Ruck C were, however, somewhat higher (i.e., a perception of a somewhat higher level of exertion) than those given Ruck B for the walking and the running activities, the 30-m rushes, and the combined obstacle and MOUT course.

The study-specific questionnaires addressed aspects of the design and functioning of the rucksacks, and here again the differences in the volunteers' responses to the two rucksacks were not great. In terms of adjustment of the rucksacks during the donning process, the number of volunteers agreeing that Ruck C was easy to adjust exceeded by two the number agreeing that Ruck B was easy to adjust. With regard to ability to adjust shoulder straps to user preference, the hip belt maintaining its adjustment during movement and not rubbing on the body, and the pack staying in place during movement, the number of volunteers agreeing that these statements applied to Ruck C was lower by one than the number agreeing that they applied to Ruck B. All volunteers were in agreement that both rucksacks were easy to doff and were compatible with wear of the IOTV, the TAP, and the ACH.

On a question regarding the ease/difficulty of performing study activities with a rucksack compared with the fighting load alone, the volunteers gave ratings on movements such as kneeling, squatting, running, and assuming and rising from a prone position. Ruck C received more negative ratings than Ruck B for running and for executing the 30-m rushes. However, there were no statistically significant differences between the ratings for the rucksacks. Further, the investigators did not observe that the study volunteers experienced greater difficulty executing any study activities in one rucksack than in the other.

The only instances of statistically significant differences between the rucksacks on the study-specific questionnaire were on a series of questions in which the volunteers were to draw on their military experiences to give their opinions of how likely it was that the rucksacks could be used successfully in various military environments. Ruck C was judged unlikely to be used successfully in a HMMWV and on wooded terrain, whereas a positive rating was given to Ruck B for both these environments.

For each rucksack, the Soldier-volunteers were asked to list the features they liked most and those they disliked most. In selecting their preferred rucksack, the volunteers were also asked to list why they selected that rucksack. There were some responses to these questions that might be suggestive of the reasons that only one volunteer selected Ruck C as his preferred rucksack. Some volunteers stated that the foam cylinders on the Ruck C pack bag were uncomfortable, an observation that was also made by the Soldiers who participated in the field testing of the initial rucksack prototypes (Roberts, 2010). Ruck B to a greater extent than Ruck C received positive comments in the current study regarding distributing the load well on the body. There were also positive comments regarding Ruck B being stable on the body and not moving vertically or laterally as physical activities were being performed. It can be posited that these particular features cited by the volunteers were related to the differences in the MOI characteristics of the rucksacks, but data were not obtained in the current study that allow analysis of the effects that MOI may have had.

The earlier field testing included assessments of the initial prototypes of the rucksacks with regard to M4 carbine use (Roberts, 2010). At one of the two test sites, a live fire operation was conducted. At the other, participants assumed firing positions and sighted the M4, but did not fire it. Observations from both test sites indicated that participants were able to assume the proper body position, but could not pocket the weapon; the butt of the weapon slipped off the shoulder straps. Further, in the prone firing position, there were some reports of the rucksack

contacting the brim of the helmet, making it difficult to raise the head and pushing the helmet down toward the eyes (Roberts, 2010). The Soldier-volunteers in the current study assumed standing, kneeling, and prone firing positions and attempted to sight the simulated M4. The observations made were the same as those reported from the field testing of the initial prototypes, and they applied to both Rucks B and C. Regarding difficulty pocketing the butt of the weapon, it was observed that the volunteers placed the butt against the upper arm. The difficulty pocketing the weapon could not be attributed solely to the shoulder straps of the rucksacks; the shoulder portion of the IOTV also contributed to the difficulty.

Although Ruck B was the preferred rucksack in the current study, the Soldier-volunteers cited some negative features of that rucksack that were related to the straps. Like the Soldiers who participated in the field testing of the initial prototype of Ruck B (Roberts, 2010), the volunteers in the current study mentioned that the straps were too long and became tangled. It was also observed that the straps of Ruck B caused some confusion during donning of the rucksack, with the volunteers mentioning that the straps got in the way. Further, the shoulder straps of Ruck B were reported to be somewhat difficult to adjust. Observations by the investigators indicated that the volunteers pulled directly downward on the straps to tighten them, whereas adjustments required that the straps be pulled toward the back. The volunteers became accustomed to adjusting the straps in this manner. However, they stood in place to do this, and it is not known whether the volunteers would find it easy to accomplish adjustment of the straps while underway during a foot march.

During the earlier field testing, the initial prototype of Ruck B was equipped with a different hip belt than was used here (Roberts, 2010). Several questions were posed to the volunteers in the current study regarding the hip belt now on Ruck B. The responses were positive with regard to the hip belt staying in place, staying adjusted, and not rubbing or irritating the skin. In the current study, a rucksack was not worn for more than approximately 15 min at a time. Thus, although the feedback on the Ruck B hip belt was positive, it is not known how acceptable Soldiers would find the belt to be during prolonged use.

CONCLUSIONS AND RECOMMENDATIONS

The 17-kg fighting load worn throughout the study represented 23% of the mean nude body mass of the volunteers. The addition of either rucksack prototype (Ruck B or Ruck C), each weighing 23 kg, increased the external load being borne on the body to 53% of the volunteers' mean nude body mass. The data obtained on energy consumption, gait biomechanics, and maximal performance revealed significant differences between the fighting load alone and the fighting load plus either rucksack. The additional mass on the body imposed by the loaded rucksacks resulted in higher energy consumption per unit body mass during walking, higher magnitude GRFs per unit body mass during walking and running, and slower times to complete Soldier-relevant physical activities. The findings from this study are evidence of the detrimental impacts that carrying external loads have on the fighting ability and operational effectiveness of Soldiers and emphasize the importance to the success of military operations of minimizing the load borne by the individual Soldier.

The comparisons of Rucks B and C with regard to the quantitative measures of energy consumption, gait biomechanics, and maximal performance did not reveal significant differences between these rucksacks. The pack bags were equally weighted for the current study and were of similar size and shape. Measurements of inertial properties also revealed that Rucks B and C had similar COMs. All these elements could have contributed to the dearth of statistically significant differences between the rucksack prototypes in the analyses of the quantitative measures. From the perspectives of the volunteers, however, there were apparently substantial differences between the two rucksacks: Six of seven volunteers selected Ruck B as the rucksack they would prefer to use in the future.

The volunteers' responses to the questions posed regarding the design and functioning of the two rucksacks did not reveal extensive differences between Rucks B and C to explain the definite preference for Ruck B. There were indications that the foam cylinders on Ruck C were found to be uncomfortable and that Ruck B was considered positively for stability of the load and for not moving vertically or laterally as physical activities were being executed.

The overall results of this study favored Ruck B as the design for a medium rucksack. There were, however, some aspects of Ruck B in need of improvement or further testing:

- The webbing of the Ruck B shoulder straps was excessively long and became tangled. The length of the straps was also viewed negatively by the volunteers as they attempted to locate the correct straps to adjust as they donned the rucksack.
- The direction of adjustment of the Ruck B shoulder straps was not intuitive. The volunteers pulled directly downward on the straps when they should have been pulling toward the back. They also made the strap adjustments while standing in place. In field use, the straps should be adjustable while the Soldier is underway.
- The volunteers were not able to properly shoulder the M4 carbine when wearing Ruck B or Ruck C with the IOTV, though the rucksacks were not solely responsible for the inability. The straps of the IOTV also contributed to the difficulty. However, the observation made in the current study that the volunteers placed the butt on the upper arm, along with a report from the earlier field testing that the butt slipped off the shoulder

as Soldiers attempted to pocket it, highlights the need to ensure that portions of armor vests and load-carriage gear passing over the shoulders do not compromise Soldiers' ability to aim their weapons properly.

- The hip belt on Ruck B, which was added for the current study (i.e., was not included on the Ruck B prototype that was field tested prior to this study), appeared to be acceptable to the volunteers in terms of staying in place and staying adjusted as physical activities were carried out. It was also judged not to rub or irritate the skin. However, on some volunteers, the hip belt passed around a portion of the torso covered by the IOTV. In such instances, it is not likely that the belt served to transfer the load weight to the wearer's hips. The rucksack was worn for only short periods of time during this study. Thus, it cannot be predicted whether opinions regarding the hip belt would have remained positive after prolonged wear.

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APPENDIX A

Sample of the Borg Rating of Perceived Exertion Scale

(Reprint of original)

Volunteer Number:______ Date:_________ Test Condition:___________

Borg Scale

RPE	**Exertion**
6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Instructions for Borg Rating of Perceived Exertion (RPE) Scale

While doing physical activity, we want you to rate your perception of exertion. This feeling should reflect how heavy and strenuous the exercise feels to you, combining all sensations and feelings of physical stress, effort, and fatigue. Do not concern yourself with any one factor such as leg pain or shortness of breath, but try to focus on your total feeling of exertion.

Look at the rating scale below while you are engaging in an activity; it ranges from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion." Choose the number from below that best describes your level of exertion. This will give you a good idea of the intensity level of your activity, and you can use this information to speed up or slow down your movements to reach your desired range.

Try to appraise your feeling of exertion as honestly as possible, without thinking about what the actual physical load is. Your own feeling of effort and exertion is important, not how it compares to other people's. Look at the scales and the expressions and then give a number.

9 corresponds to "very light" exercise. For a healthy person, it is like walking slowly at his or her own pace for some minutes

13 on the scale is "somewhat hard" exercise, but it still feels OK to continue.

17 "very hard" is very strenuous. A healthy person can still go on, but he or she really has to push him- or herself. It feels very heavy, and the person is very tired.

19 on the scale is an extremely strenuous exercise level. For most people this is the most strenuous exercise they have ever experienced.

Borg RPE scale

APPENDIX B

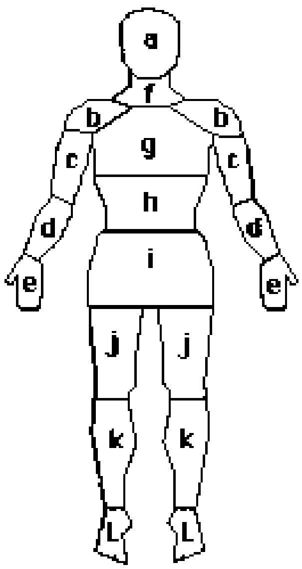
Sample of the Rating of Pain, Soreness, and Discomfort Questionnaire

(Reprint of original)

Discomfort Questionnaire:

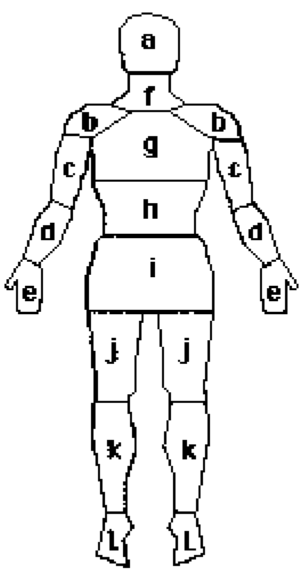
Volunteer Number:______ Date:________ Test Condition:___________

1. Rate the degree of PAIN, SORENESS, or DISCOMFORT that you are currently feeling for Body Parts A through L. Do so for the FRONT and the BACK of the body.



FRONT of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐



BACK of Body

	a	b	c	d	e	f	g	h	i	j	k	L
NONE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SLIGHT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
MODERATE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SEVERE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
EXTREME	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐